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FURTHER STUDIES OF COTTON ROOT ROT IN ARIZONA, WITH A DESCRIPTION OF A SCLEROTIUM STAGE OF THE FUNGUS [1]

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INTRODUCTION

During recent years investigators have obtained conclusive evidence that the destructive plant disease of the Southwestern States, often called Texas root rot, is caused by the fungus *Phymatotrichum omnivorum* (Shear) Duggar (*3*).[2]

Although much study has been given to this disease, little information is available in regard to the life history of the fungus, its physiology, or the factors that effect its distribution. Recent studies have added much to the general knowledge of the habits of the fungus and its ecology, but many important questions remain unanswered.

In previous publications the writers (*6*, *7*, *8*, *9*) have reported the results of experiments which indicated that the disease could be controlled to a limited degree in cotton and alfalfa fields by the use of organic manures, trench barriers, and soil disinfectants. The behavior of the fungus in artificial cultures containing different kinds of plant roots and the partial success obtained in efforts to inoculate healthy plants with pure cultures were also reported. Since the fact was established that the fungus grew readily on dead plant tissues in cultures and that active mycelium on decayed roots and stumps of native plants gave rise to root-rot infection in cultivated crops when planted in virgin soils, it was suggested that the fungus might be capable of existing in the soil as a saprophyte.

During the season of 1928 additional information was obtained which appears to be of sufficient importance to justify a further report. The investigations included a study of the types of food on which the fungus may subsist, the manner in which it spreads through the soil, and the depth at which it may function. Further inoculation and control experiments were conducted, and a better knowledge of some of the phases of its life history was obtained. The discovery of what appears to be a true sclerotial development of the fungus in soil cultures seems to be of special importance in the bearing it may have on the effectiveness of control measures, such as rotation of crops, fallowing, flooding, and chemical treatments. The results of these investigations and observations are reported in this paper.

CULTURES OF THE ROOT-ROT FUNGUS ON DEAD ROOTS

Although there is ample proof of the pathogenic character of the fungus *Phymatotrichum omnivorum*, there appears to be a lack of

[1] Received for publication Mar. 22, 1929; issued November, 1929.
[2] Reference is made by number (italic) to "Literature cited," p. 675.

agreement among investigators as to whether it is a facultative parasite as originally described by Shear (*15*) or an obligate parasite which can not long survive in the soil independent of living hosts. Taubenhaus and Killough (*16*) state that "the causal organism in nature dies out with the death of its host" and that it "is unable to maintain itself on dead organic matter or in the soil." On the other hand, Peltier, King, and Samson (*13*), Ratliffe (*14*), and King and Loomis (*9*) have

FIGURE 1.—Effect of inoculations with pure cultures of the cotton root-rot fungus on Acala cotton plants grown in tanks of disease-free soil. The plant on the left was inoculated on August 9 with the contents of a quart fruit jar containing a pure culture of the fungus on dead tissues of cotton plants in alternate layers with sand. The inoculated plant wilted on August 14, and the disease was then communicated through the soil to the other plant, which wilted on August 26

reported observations wherein roots that had been dead for a long period were covered with root-rot mycelium which was the source of conidial mats, in some cases producing centers of infection.

Since it was apparent that the effectiveness of any cultural methods of control would be likely to be influenced by the question whether the fungus was able to maintain itself in the soil independent of a

living host, it seemed important to the writers to endeavor to establish final proof. A large number of pure cultures were prepared by inserting bits of dissected pseudosclerotia from a type culture into quart fruit jars containing alternate layers of sand and dead roots and stems of cotton plants. To eliminate the possibility of extraneous fresh-plant tissues being present in the culture jars, the sand used was thoroughly sifted and heated to a high temperature before final sterilization. Only such plant tissues were selected as had reached an advanced stage of decomposition, having been cut into sections and buried in the soil for one or two years.

When the cultures had grown until all of the root and stem tissues were covered with the mycelium and large strands had reached the bottom of the jars, the contents were removed and inserted in a hole 6 or 8 inches deep prepared alongside the taproots of normal cotton plants grown in iron drums and tanks. The drums contained about 6 cubic feet of soil free from root rot, and two cotton plants were grown in each. The tanks contained 30 to 50 cubic feet of soil, and each had four plants. Six out of nine inoculations made in this manner were effective in killing the plants inoculated in a period of 5 to 16 days. (Fig. 1.) The disease was immediately communicated to the adjacent plants in the same containers, and several of them died within a few days. The fungus was reisolated from the first plant that died and was cultured in tubes and fruit jars. Seven cotton plants in a field free from root rot were inoculated in the same manner about September 1. Five of these died before October 2, and the disease was transmitted to adjacent plants. Large numbers of field inoculations were also made at various times during the summer, using one or two 4-inch sections from the taproots of recently infected plants. These were effective in killing 12 to 27 per cent of the treated plants.

In the light of these results there seems to be no doubt that under natural conditions in the soil the fungus is capable of attacking the living tissues of healthy plants after subsisting for long periods on dead tissues only.

GRASS AND DATE PALM HOSTS OF THE FUNGUS

Though some students of the root-rot disease have suspected that the fungus might live on the roots of grasses or other monocotyledonous plants and thus remain in the soil for long periods without killing any plants, there seems to have been no evidence to support this theory until June, 1928, when the writers discovered the root-rot mycelium extensively distributed over the roots of date palms at Sacaton, Ariz., and in California. (Fig. 2.) A short time later it was found on the roots of Johnson grass and Bermuda grass in proximity to dying alfalfa plants. On the larger date-palm roots and on the sheaths and rootstocks of Johnson grass the strands were firmly attached, creeping over the surface in the same characteristic manner as on the roots of the most susceptible hosts. On the fibrous roots of the grasses the strands for the most part ran over the surface longitudinally and were not easily detected.

In one date orchard in California the root-rot mycelium was found in abundance as deep as 4 feet on many of the roots of the date palms in the outside row. No live roots other than those of the date were found in the extensive excavations that were made in this orchard,

but a trench dug about 25 feet outside the infected row of date palms disclosed the fact that the infection originated from a row of almond and fig trees which once stood in what is now a roadway, adjacent to the date planting. These trees had been dug one at a time as they were killed by root rot through a period of several years, the last almond tree having been removed in 1927. Many decayed roots of these old trees were exhumed in digging the trench, and active mycelium was found pervading the decomposed material even at a depth of 4 feet. Frequently live date roots had penetrated through the old soft decayed roots, and invariably these were covered with root-rot strands.

Another observation on the relationship of grass crops to the root-rot disease was made on the Indian School farm at Sacaton in July, 1928. A 10-acre alfalfa field in which practically all of the plants had been killed by root rot was plowed in 1924 and planted to grain sorghums. Three successive crops of sorghums were grown, and the field was replanted to alfalfa in the winter of 1927–28. During the early summer months of 1928 frequent observations were made in this field, so that the first indications of recurrence of the root-rot disease

FIGURE 2.—Date root with a coarse strand of *Phymatotrichum omnivorum* growing along the surface and producing numerous fine strands

might be detected. Several small circular areas of dying plants were noted on July 20. Near the centers of several of these infected spots were clusters of young sorghum shoots which originated from old sorghum root crowns that had been turned over by the plow in breaking the land, but not killed. Some of these old crowns were split open and large root-rot strands were found creeping over the partly decayed tissues on the inside.

SELECTIVE FEEDING OF THE ROOT-ROT FUNGUS ON ROOTS OF DIFFERENT PLANT SPECIES

Several investigators (*1, 3, 9, 13, 16*) have reported that the root-rot fungus grows well on cooked vegetables and various other media, but apparently no serious attempts have been made to determine to what extent the organism shows discrimination in the types of plant materials on which it will grow or to ascertain whether there are any kinds of roots on which it fails to develop. After finding the mycelium in nature occurring in great abundance on the roots of

date palms and some of the common grasses, the writers attempted to grow the fungus on sterilized roots of these plants. Small pieces of pseudosclerotia were transferred from pure cultures to a series of tubes containing cooked roots of date, Johnson grass, Bermuda grass, barley, and corn. The fungus developed rapidly on the date roots and covered the contents of the tubes in a few days. On the roots of Johnson grass and Bermuda grass the development was much slower, but growth was continuous in some sealed tubes for three or four months, and all of the roots became enveloped with mycelium. The growth on barley and corn roots was extremely slow, but continued for several months.

When the cultures were 81 days old the contents of one tube each of date roots, Johnson-grass roots, and Bermuda-grass roots were transferred to sterilized quart fruit jars, each containing a layer of cotton roots on top of a 5-inch layer of moist sand. A vigorous growth resulted, and in a short time the mycelium had entirely covered the roots and had invaded almost every portion of the sand.

In order to obviate the chemical changes in the roots brought about by steam sterilization and to have the nutritive material in a state as nearly identical as possible with that found in nature, a series of tubes was prepared containing date roots that had been sterilized by immersion for a few seconds in alcohol. Inoculum material from pure cultures on date roots was added to these tubes, and the mycelium soon spread to the new material and grew vigorously for several weeks.

In comparing the development of mycelium on cultures of various roots it was observed that in tubes containing fresh citrus roots the mycelium failed to grow in contact with the citrus tissues, and if other nutrient material was present the hyphae avoided contact with the citrus roots and grew only on the other material. (Fig. 3.) Repeated trials were made and larger containers were used, but the results were always the same. No growth resulted on fresh sterilized tissues of citrus roots. This behavior seems somewhat significant in that citrus is one of the few orchard crops that is reported to have a high degree of resistance to root rot. It has been reported from Texas that young citrus trees have been killed by the disease, although well-established trees have not been known to die.

The fungus made the most rapid development on cooked roots of such plants as cotton, alfalfa, cowpea, peach, and *Malva parviflora*. The growth was much slower on roots of tamarisk, pomegranate, peppertree, mesquite, groundcherry, and sunflower. Upon these the pseudosclerotia were slower in developing.

DEPTH OF FUNGUS ACTIVITY

The depth at which the root-rot fungus may function would seem to be a matter of importance in connection with any control measures that are undertaken. However, it appears that no systematic studies have been made along this line. McNamara and Hooton [3] report that open trenches 2 feet deep, prepared in advance of the disease, were effective in checking its progress in a cotton field. Prior to 1928 the writers had found the mycelium on cotton roots to a depth of 36

[3] McNamara, H. C., and Hooton, D. R. STUDIES OF COTTON ROOT ROT AT GREENVILLE, TEXAS. [Unpublished manuscript.]

inches and on peach roots to a depth of 40 inches, but most observations have shown that it seldom destroyed or was present on the roots of closely planted field crops at a depth greater than 30 inches. In July, 1928, an extensive series of trenches was made around an infected area in California in an attempt to isolate the disease and prevent its spread to new areas. On the east side of what was thought to be the infected area no indicator plants were present, but one of the trenches, which was 414 feet long and 3 feet deep, was contiguous to a date orchard in which clean cultivation was practiced. A few

FIGURE 3.—View looking down into a culture tube containing two types of plant roots as food media, with a pure culture of *Phymatotrichum omnivorum*. Two sections of citrus root are seen at the left, surrounded but not touched by the white mycelium of the root-rot fungus which developed from two sections of cotton root at the right. The cotton sections became completely hidden by the mycelium, while the citrus sections remained exposed for their entire length. × 4½

feet on the other side of the trench was a bare roadway in which a row of almond trees and fig trees had once stood, but which had been dug one at a time as they were killed by root rot, the last being removed in 1927. Shortly after the trench was dug it was filled with water, and a few days later numerous conidial mats appeared on its walls, some at the bottom, 3 feet from the surface. The locations of the almond and fig trees were clearly defined by large patches of these mats which produced almost solid formations several square feet in extent wherever the trench transected numerous dead tree roots close together. The depth of the trench was increased in places to 6 feet,

and in the excavations root-rot strands were found on the dead roots of almond and fig and the live roots of date at a depth of more than 4 feet.

Soon after the trench was deepened it was irrigated again, and a new crop of spore mats appeared, the lowest at a depth of 4½ feet. The mats spotted both walls of the trench through most of its length of 414 feet, with two short nonspotted intervals amounting to 44 feet. In one place where the ditch transected rotted roots of a dead pistache tree that had been dug five years previously, both walls of the trench were covered with extensive patches of mats.

In another short trench dug 6 feet deep near a group of dead pistache trees, live strands of the fungus were found on the decomposed roots at a depth of 5⅝ feet, and spore mats almost completely covered the walls of this trench to a depth of 5 feet. (Fig. 4.) Some weeks later the trench was filled again with water, and shortly afterwards a new crop of mats appeared. This time they extended over the old mats, covering the walls of the trench almost completely, and appeared even at the bottom of the trench 6 feet below the surface of the ground. In this way the trenches proved to be of much use in definitely locating the disease in this area in the absence of indicator plants on the surface. In every instance where the plants near the trenches indicated the disease, or wherever there was a history of the disease among orchard crops, and even where the trees had given place to bare roadways, spore mats appeared in abundance. None, however, were seen in the trenches in areas where the disease had never been in evidence.

BARRIER METHODS OF CONTROL

During the spring and summer of 1928 further trials were made with barriers in attempting to check the advance of the disease in infected spots in alfalfa fields. Instead of using open trenches, which were found to be impracticable under irrigation methods, the trenches were refilled with soil that had been mixed with about 1 part fuel oil by weight of oil to 10 of soil. In order to conserve oil and labor a narrow trenching spade 6 inches wide by 18 inches long was used in removing the soil. (Fig. 5.) The barrier experiments were conducted in alfalfa fields because the limits of the disease were so definitely marked in this crop and the spots were more circular in outline. The disease could thus be observed over a longer period than is possible in cotton fields. The trenches were approximately 3 feet deep and were placed 3 feet in advance of the active zone of disease, which was indicated by the rings of recently wilted plants. Two trenches, of semicircular shape and about 100 feet long, were prepared on May 15, before the disease had killed any plants. The zone of active mycelium, however, was easily ascertained by examining the roots on the outside margins of circular bare spots where plants had been killed in the previous season. A part of the old diseased area behind the active margins, where nearly all the alfalfa plants had been killed in previous years, was plowed and planted to cowpeas in order to observe any reverse movement of the fungus or any renewed centers of infection. On June 13 the length of one of the barriers was increased to 180 feet.

Within a month after the barriers were prepared the disease, as shown by dead plants, had reached the oiled earth of the 180-foot

FIGURE 4.—Conidial mats of *Phymatotrichum omnivorum* lining the side of a trench 6 feet in depth. The mats which formed near the bottom of the trench had been obliterated by rodents at the time of photographing. The actively growing part of these masses is indicated by the white bands at the margins of the mats. In the same vicinity numerous formations of this kind appeared in trenches distant from any living plants, and where no live plant-root tissues were in evidence in the soil but dead root material was found in abundance

trench in several places. On September 5 it had killed practically all of the plants behind this trench, but there was no indication of crossing over except in one place near the end where one or two

FIGURE 5.—Preparation of a barrier trench, to be filled with mixed oil and earth, about 3 feet in advance of the root-rot disease in an infected alfalfa field. The trench was dug with a narrow spade in order to conserve oil and labor

plants were dead on the outside of the barrier. (Fig. 6.) The disease was slower in reaching the oiled trench in the other spot, but on September 1 it was observed that only a few plants remained alive on the inside of the semicircular oiled barrier, and no dead plants were found on the outside.

On July 12 trenches were dug around two small circles of root rot in another alfalfa field. These were placed 3 feet outside of the band of recently dead plants and were dug only 26 inches deep. Long sheets of galvanized iron, 26 inches wide, were dropped on edge into these trenches, with the ends overlapping so that the diseased area

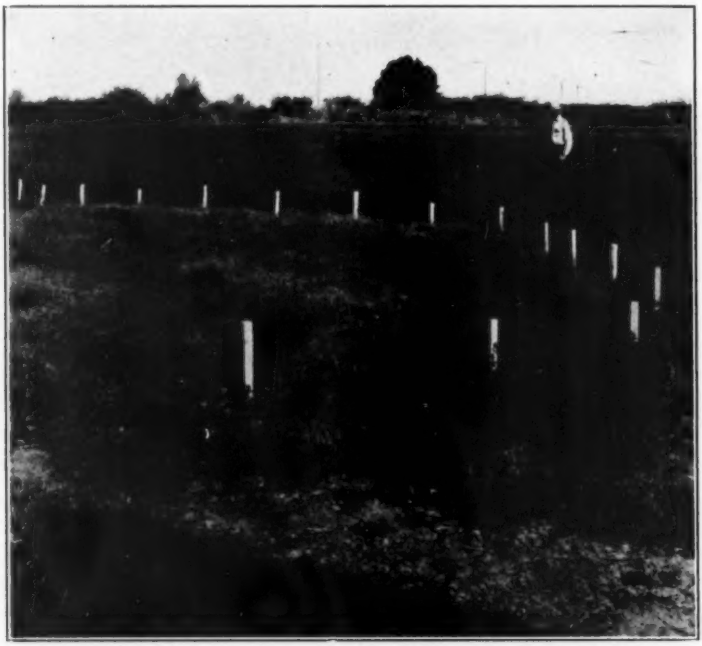

FIGURE 6.—A large root-rot spot in an alfalfa field where the spread of the disease was checked by an oiled-earth barrier 3 feet deep and 6 inches wide, indicated by the white stakes. The barrier was prepared on June 13, 3 feet in advance of the outer margin of the area infected the previous year. Nearly all of the alfalfa plants behind the barrier were killed before September 5, but none was infected on the outside of it when the spot was photographed on October 29

was completely encircled and isolated by an iron barrier 26 inches deep. The metal sheets were pressed firmly against the inside wall of the trench and the soil was replaced. All of the plants on the inside of the barriers were killed within five weeks, but in spite of the rather shallow depth of the barriers no plants on the outside were attacked, although the disease was active in other circles a few feet away for three months after its spread in the inclosed areas was checked by the barriers. Other barriers of oiled earth and galvanized iron were prepared on August 18, and at the end of the season no diseased plants were observed on the outside of the barriers, whereas all of those within had been killed long before the end of the season.

CLEAN-FALLOW EXPERIMENTS

It has been suggested by some investigators that the root-rot organism might be starved out by keeping the soil free from all living plant tissues for an extended period of time. McNamara (*11*) reported that a clean-fallow treatment for a period of two years at Greenville, Tex., was effective in controlling the disease. Later experiments at Greenville and similar experiments at other places in Texas, however, have not been so encouraging. Clean-fallow experiments were begun at Sacaton, Ariz., in 1925. An area of half an acre, comprising plots C3–1 and C3–2, on which the cotton crop of 1925 was badly infected, was maintained as a clean fallow during the years 1926 and 1927 and replanted to cotton in 1928. Plot C3–3, an adjacent area of one-fourth acre, on which only 3.5 per cent of the cotton plants were infected in 1925, was planted to corn in the summer of 1926 and to Canada field peas in the fall of 1926. In March, 1927, the peas, which showed no evidence of infection, were plowed under, and the area was maintained as a clean fallow until March 20, 1928, when it was replanted to cotton.

In maintaining the clean fallow, plots C3–1 and C3–2 were plowed once at the end of each summer after the initial breaking of the land, making three plowings in all. These were made with a moldboard plow which penetrated to a depth of 6 or 7 inches. Plot C3–3 was plowed early in 1926 to turn under the dead plants of the 1925 cotton crop, and a crop of cornstalks was also plowed under late in the same year. In 1927 this plot was plowed twice, the first plowing being necessary in March to turn under the crop of peas. In addition to the plowing operations, all three of the plots were gone over with a disk cultivator 8 or 10 times each year to keep down the growth of weeds and grass which came up after rains. Between diskings the plots were frequently inspected by laborers who removed all seedling weed growth and exhumed many tubers of *Rumex hymenosepalus* with hand implements.

During the months of June, July, and August, 1928, all of the cotton plants of these three plots were inspected daily, and a record was kept of all the separate points of infection that appeared, as indicated by the dying of plants at some distance from any that had died previously. The first dead plants were observed on June 17. The observations were continued until August 10, at which time 106 centers of infection had appeared on plot C3–1, 78 on plot C3–2, and 38 on plot C3–3.

During the early part of the summer an attempt was made to control the disease by digging out the fungus. The plots were inspected every morning, and plants that had wilted were immediately dug up, together with the adjacent plants on either side, if any infected roots were observed. The soil was removed to a depth of about 18 inches and hauled away. The sides and bottom of the excavations were then thoroughly sprayed with a strong disinfectant, and disease-free soil was brought in to refill the holes. By the middle of August it was apparent that little progress was being made by this method, as the disease continued to spread from about two-thirds of the treated centers, indicating that the advance mycelium had extended beyond the excavations; and the practice was discontinued.

On November 21 a survey was made of the diseased areas in these plots and a map was prepared showing the location of infected and

noninfected areas. The extent of infection in these plots in 1925 and after the fallow treatment in 1928 is shown in Figure 7.

The infected area, as shown in Figure 7, maintained approximately the same configuration after fallowing as before on plots C3–1 and C3–2, although the number of scattered patches of healthy plants in the large infected areas was greater in 1928 than in 1925. The percentage of infected area on plot C3–1 was 61.6, compared to 67.4 in 1925, whereas on plot C3–2 the infected area had increased from 30.5 to 41.3 per cent. On plot C3–3, which was fallowed only one year, following corn and a winter cover crop, the disease had increased considerably in extent, affecting the plants on 19.2 per cent of the area in 1928 as compared to 3.5 per cent in 1925.

It is apparent that the fallow treatment had no effect in reducing the amount of infection. The margins of the diseased areas in 1928

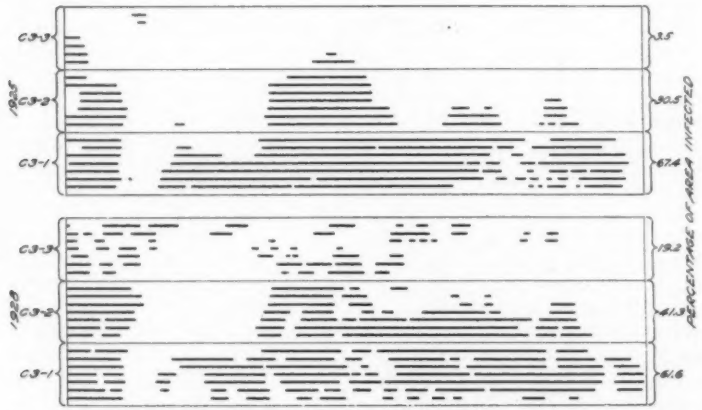

FIGURE 7.—Diagram showing the extent of root-rot infection on three quarter-acre plots of cotton in 1925 and 1928, before and after clean fallowing, at the United States Field Station, Sacaton, Ariz. Plots C3–1 and C3–2 were fallowed in 1926 and 1927, and plot C3–3 was fallowed in 1927, following successive crops of corn and winter peas in 1926. No material reduction of the area infected followed the fallow treatment, and the infected spots occupied about the same locations as before

closely coincided with the margins in 1925, except that in most cases they had extended a few feet farther. This persistent behavior in the absence of any live host plants for a period of two years suggests that the organism was maintained under such conditions by some resistant form of mycelial development or that it can support itself from dead plant tissues. Extensive excavations were made after the 2-year fallow treatment to determine what types of plant tissues remained in the soil. Cross-section trenches were dug 2 to 3 feet deep at several places, but the only plant material exhumed was in small fragments and in such an advanced stage of decomposition as to be easily crumbled between the fingers. The cotton plants of the 1925 crop, as they were of small size, no doubt disintegrated more rapidly than ordinarily is the case under Arizona conditions. Since there was no evidence that any living tissues were present and as there was no dead material sufficiently large to give protection to a delicate mycelium, the evidence seems to indicate the presence of a highly resistant and resting form of the organism.

DEVELOPMENT OF PSEUDOSCLEROTIA

In 1893 Atkinson (*2*) reported sclerotiumlike bodies which developed in his cultures of Ozonium (Phymatotrichum). He described these as "from very small to 3 millimeters in diameter, whitish and woolly, finally becoming of the same color as the filaments of the fungus." Taubenhaus and Killough (*16*) also reported this form, which they termed "pseudosclerotia," as appearing singly or in large masses in cultures on various media and on host plants in natural surroundings. The writers have commonly observed the type which is found on infected roots (chiefly at the lenticels) and which several investigators (*2, 4, 5, 12, 16*) have described as "wartlike." However, the structure and size of the pseudosclerotial formations which develop commonly in artificial cultures are so different from these small accumulations of hyphae found in nature that it is difficult to consider them as analogous forms.

In pure cultures the growth of the pseudosclerotia depends on a properly moist food supply. With foods such as sweet potato, turnip, and the roots of cotton, alfalfa, and peach, on which the mycelium grows readily, pseudosclerotia may begin to form soon after the mycelium becomes well established on the roots. On foods on which the mycelium does not grow readily, pseudosclerotia may not form, or if they do it is very slowly, and only small masses are developed. They have been observed to form after several months on sterile roots of date palm, Bermuda grass, Johnson grass, and barley contained in culture tubes sealed with beeswax and paraffin.

In the ordinary culture tubes containing small sections of cotton or other suitable roots it has been observed that the pseudosclerotia may continue to develop until nearly all the space in the tube is occupied and the roots which supplied the food become shriveled and greatly reduced in size. In large containers, such as 1-quart or 2-quart fruit jars, containing sterile cotton roots and sand, single masses 20 millimeters or more in diameter and 5 or 6 millimeters in thickness have been developed, and the surface of the sand and roots has become almost completely covered by these masses. (Fig. 8.) These structures are obviously also aerial in character, as they form on the strands that have grown along the glass surface of the containers, at some distance from any food supply. They are also sometimes observed in cavities within the soil or sand cultures, but are apparently unable to develop where the soil is compact.

The pseudosclerotial structures become deflated in drying, and if allowed to remain in this condition for many months at ordinary room temperatures the hyphae become brittle, and in this state attempts to revive the fungus have thus far been unsuccessful.

A convenient method for multiplying cultures has been developed by the writers, making use of entire small fresh pseudosclerotia or fragments of the large ones. In the latter case enough material often can be obtained from a single body to propagate 25 or more cultures, and a quart fruit jar frequently affords sufficient material for several hundred cultures. These fragments seldom fail to grow, whereas failures are not uncommon where loose wefts of mycelium are used. In the incubator at 25° C. hyphae may begin to appear from the fragments in new cultures within three or four days.

Experiments to determine the length of time that these pseudosclerotia remain viable have not been completed, but it is apparent

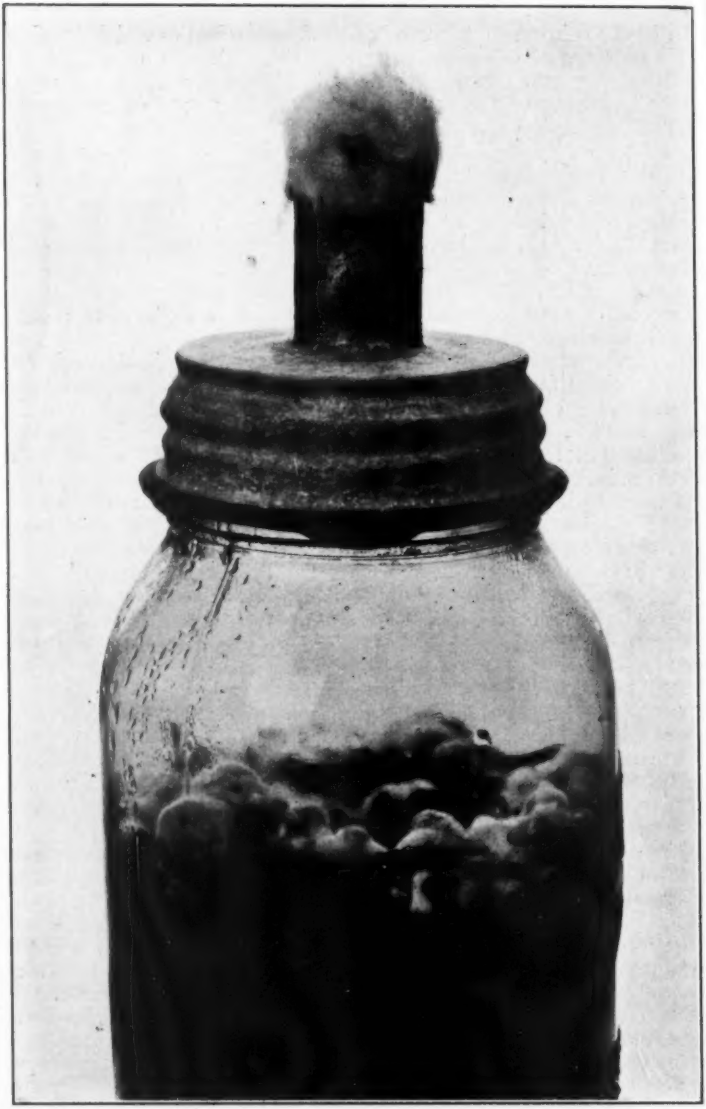

FIGURE 8.—Pure culture of *Phymatotrichum omnivorum* on dead cotton roots underlaid with moist sand, in a quart fruit jar equipped with a special lid. This jar was inoculated on October 4 with the fungus on a small section of date root from an 81-day-old date-root culture. The photograph shows the numerous large masses of pseudosclerotia which had developed by November 10 and almost completely hid the cotton roots and the surface of the sand. Such a culture contains sufficient pseudosclerotial material for preparing innumerable cultures of the fungus, and entire cultures of this type were used in inoculating healthy cotton plants

that under optimum conditions they may be kept for several months and still develop further mycelial growth when transferred to a fresh food supply.

A TRUE SCLEROTIAL STAGE OF PHYMATOTRICHUM OMNIVORUM

In describing the characters of the strand hyphae of the root-rot fungus, Duggar (*3, p. 19*) states that "they are more or less sclerotial and are doubtless an important factor in the persistence of the fungus in the soil." Taubenhaus and Killough (*16, p. 73*) apparently did not interpret this statement as applying to the strand hyphae primarily, as they comment on it as follows:

> It is true that *Phymatotrichum omnivorum* does produce on the host and in pure culture sclerotialike bodies. These, however, are much of the nature of pseudosclerotia, and do not seem to be able to survive during the winter months on a dead host or in the soil. All our evidence on hand tends to show that *Phymatotrichum omnivorum* is unable to live as such in the soil as ordinary mycelium without the presence of a living host.

The writers have recently observed a hitherto undescribed type of mycelial structure which developed from the strands of the root-rot fungus in pure cultures with a substratum of sand or soil. This new structure is a form of sclerotium with characters that would enable it to live through the winter or through long periods in the field without a supply of food. The first development of these sclerotia was noted late in September, concurrently with unusually low temperatures. The fungus was being grown in long glass tubes containing only moist sterile sand, with the culture introduced at one end of the tube on a small section of dead cotton root. After the strands had grown several inches from the food supply the sclerotia began to form on the coarser portions of the strands. In October large numbers of these sclerotia were developed in pure cultures of Phymatotrichum raised in quart fruit jars on sections of cotton roots lying on 5 inches of sterile moist sand. Of 27 such cultures in fruit jars, sclerotia appeared in 21.

Prior to the formation of the sclerotia and during their development all of these jars were exposed to the ordinary temperatures of the laboratory, which at night occasionally dropped as low as 65° F., with day temperatures sometimes exceeding 95°. These bodies were produced either singly or in continuous series or in distinct clusters on the large strands that had penetrated the sand below the cotton roots. (Fig. 9, A, B.) Many sclerotia appeared on the strands that descended along the sides of the jars, and their development was plainly visible through the glass. Few were produced on the surface of the sand or on the mycelium above the sand. The formation of sclerotia was continued in some jars through the winter at room temperature of the unheated laboratory, a second crop of sclerotia being produced in a few jars. In these jars new sclerotia were developed in some of the old clusters and on some of the oldest strands, as well as on younger strands.

Sclerotia also developed in several jar cultures that had been kept for two or three months in an incubator held at a constant temperature of 25° C. and in other jars kept in a steam boiler room where the temperature fluctuated between 40° and 90° F. The fact that no sclerotia developed until September or October in the jar cultures prepared in the early summer, and their occurrence almost simul-

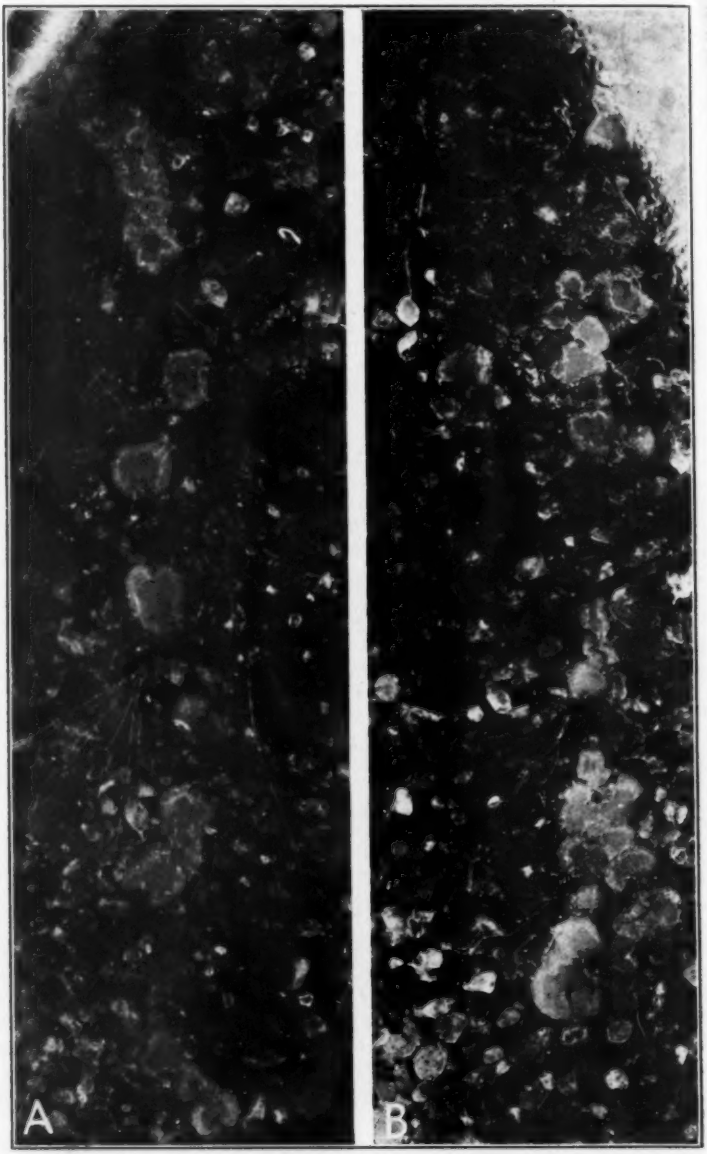

FIGURE 9.—Sclerotia developed on the strands of *Phymatotrichum omnivorum* in pure cultures in quart fruit jars. A, several large single sclerotia are shown in alignment in the middle of the photograph, while above and below them are compound formations resulting from sclerotia which started developing so close together on the strand as to form continuous series when fully grown. × 5. B, conglomerate sclerotia produced on a single coarse strand of the fungus. These represent the largest masses that have been observed. Two young sclerotia may also be seen on the white strand near the upper left-hand corner of the photograph. × 5

taneously in nearly all of the cultures, regardless of their age, when cool weather arrived, indicates that temperatures bear an important relationship to the development of sclerotia.

The sclerotia begin to develop as simple, white, elongate swellings of the larger mycelial strands (figs. 10 and 11, A), and maximum growth is attained within three or four days, with the fully developed sclerotia resembling miniature potatoes, round or ovoid in shape, and slowly changing in color through light yellow to reddish brown with age. The largest individuals were about 2 mm. in diameter, but many smaller ones were produced. In many cases the formation was so continuous along the strands that solid clusters were produced 10 mm. or more in length. The shape of some of the clusters also indicated that many of the sclerotia were developed by a budding process directly from the walls of other sclerotia (figs. 11, C, and 12), as well as from the strands themselves. (Fig. 13, A and B.) All of the sclerotia produced in two jars were carefully separated from the sand in order to count them. Although an entirely accurate count was not possible, because of the compound character of some of the clusters, it was found that at least 621 sclerotia had formed in one jar and 2,731 in the other. (Fig. 14.) The dry weight of the sand in each of these jars did not exceed 1,000 gm.

Microscopic examination of sections of the sclerotia showed that they were formed by the division and growth of the cells of portions of the large strands. This division of the cells apparently took place in the large central cells of the strands as well as in the smaller cells which surround the larger, as no continuous series of large cells of similar appearance extended through the sclerotia. (Fig. 11, A.) Sections show that the interior of the sclerotia is made up of closely packed, colorless, thin-walled cells of large and small size intermixed and varying in shape from roughly rounded to elongate oval and having no definite arrangement. (Fig. 11, B.) A view of the surface of the sclerotia presents a labyrinthine appearance caused by the very irregular or contorted shapes of the brown, moderately thick-walled cells. (Fig. 15, A, B.) From some of these surface cells, acicular hyphae, or setae, similar to those of the strands themselves, protrude at right angles, giving the sclerotia a somewhat bristly aspect under the microscope.

At the time of development of the sclerotia in the jars some of the cultures were nearly 3 months old while others were less than 4 weeks old. The inoculum used to establish the fungus in the jars in some cases consisted of pieces of pseudosclerotia while in others small sections of sterilized cotton roots, overgrown with the fungus, from type cultures, were introduced into the jars.

In a preliminary study of the viability of the sclerotia, several clusters were broken apart and the individual sclerotia placed on moist sterile cotton roots in culture tubes. The tubes were kept at a temperature of 25° C., and in a few hours a dense growth of fine, erect, white hyphae developed over the entire surface of the sclerotia in 32 of the 33 tubes. (Fig. 13, C.) More recent inoculation studies with sclerotia show that the above proportion of viability may be expected with great regularity when sclerotia are removed from cultures and placed immediately on a suitable medium.

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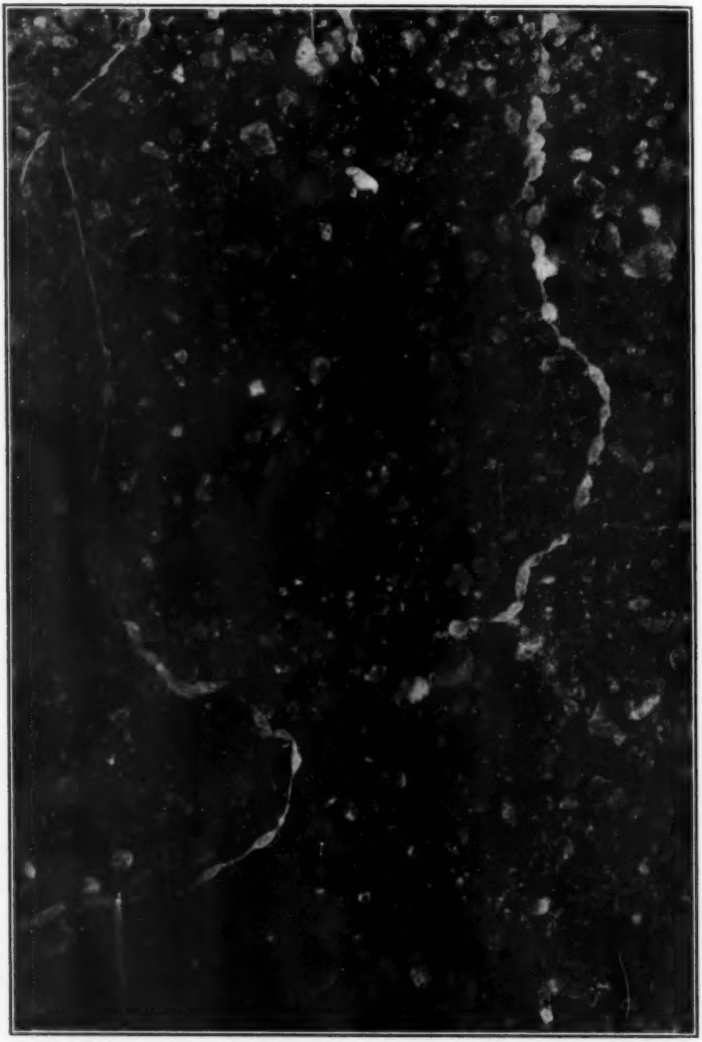

FIGURE 10.—Initial stages of sclerotial development on the coarse strands of *Phymatotrichum omnivorum* in pure culture in a large candy jar containing sand and dead cotton roots, showing the manner in which the sclerotia first appear as swellings of the large mycelial strands of the root-rot fungus. × 4½

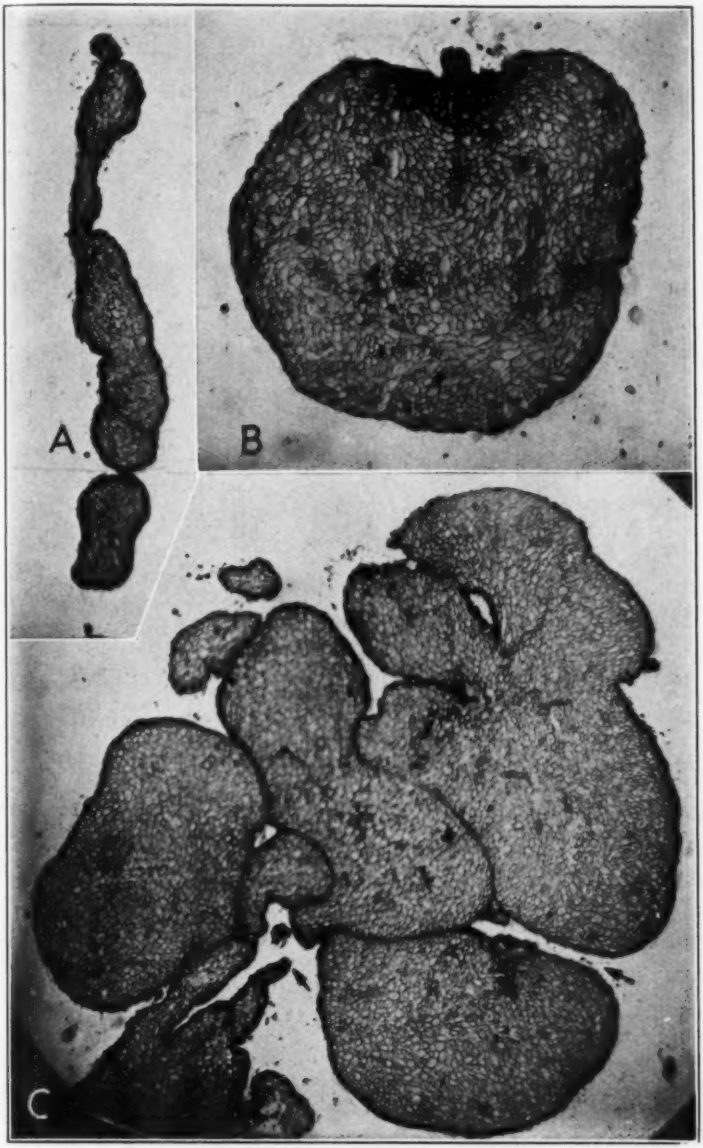

FIGURE 11.—Longitudinal sections of sclerotia of the root-rot fungus. A, a long portion of a strand which had begun developing into sclerotia. No semblance of the original strand remained except just above the middle of the long central portion of the sclerotial structure. × 30. B, a single sclerotium, showing its connection with the strand on one side, and the shapes, sizes, and arrangement of the interior cells. × 58. C, a large compound cluster of sclerotia illustrating the method by which other sclerotia bud from the sides of those produced directly from the strands. The junction of the cluster with the strand on each side is indicated by the small black arrows. × 32

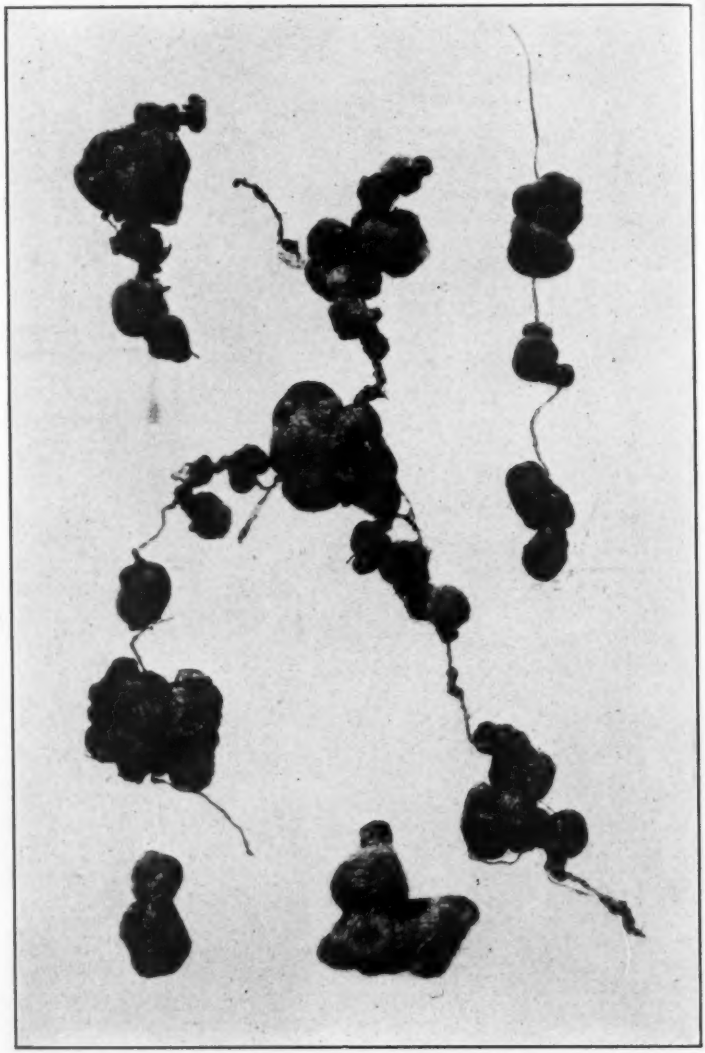

FIGURE 12.—Conglomerate masses of mature sclerotia of *Phymatotrichum omnivorum* removed from the sand in jars containing pure cultures of the fungus on dead cotton roots. The aggregate character of the sclerotia and their disposition on the strands will be noted. × 7½

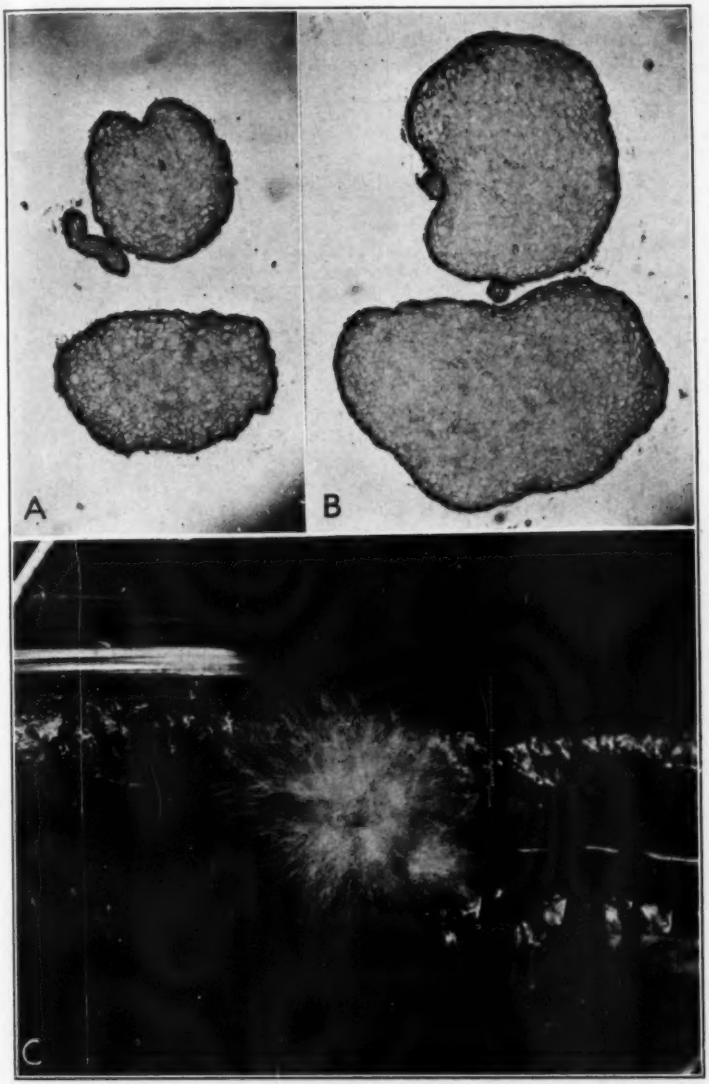

FIGURE 13.—A, Cross sections of two sclerotia and a short portion of the connecting strand. × 45. B, other cross sections of the same two sclerotia showing the junction of one end of the intervening strand with the upper sclerotium, while the other end is indicated near the point of connection with the lower sclerotium. × 45. C, single sclerotium germinating on dead cotton-root tissue in a culture tube incubated at 25° C. The dense growth of white hyphae developed in 21 hours. × 5

Within 48 hours after one of the sclerotia is placed on a cotton-root plug in a culture tube the typical coarse strands begin to form and make possible the positive identification of the mycelium without the use of the microscope. After the coarse strands appear, the cotton roots are quickly enveloped with this type of growth. In

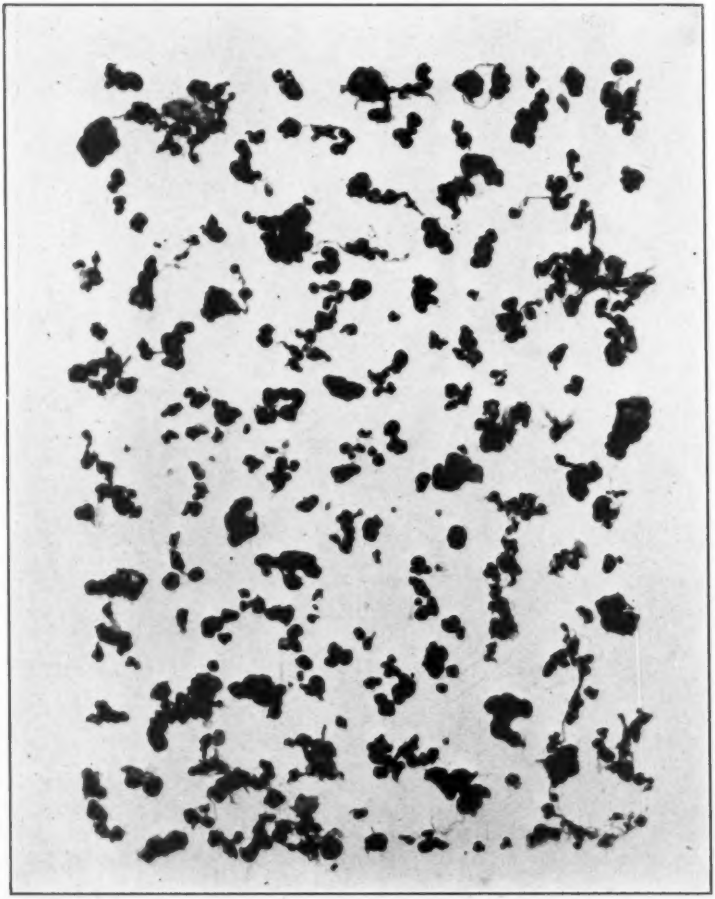

FIGURE 14.—Specimens of sclerotia of *Phymatotrichum omnivorum* representing about nine-tenths of the total number produced in the sand of a single quart fruit-jar culture. After separating the clusters into their component parts it was estimated that over 600 sclerotia, each capable of reproducing the active fungus, were produced in this small volume of sand, not exceeding 700 cubic centimeters. × 1½

several fruit-jar cultures, containing pieces of cotton roots placed on moist sand and inoculated with a single sclerotium, the same rapid development of the fungus was observed. In less than two weeks pseudosclerotia began to form, and the surface of the sand and roots was covered with a dense and almost continuous formation of feltlike material.

On November 4 the root-rot fungus was established in two long glass tubes containing sand which had been washed with sulphuric acid to remove the organic food material. A single small true sclerotium was introduced at one end of each tube. Hyphae developed in a short time and began advancing along the tubes. The daily progress of the hyphae is given in Table 1, reference to which shows that the growth in one of the tubes was quite irregular throughout its entire course. The growth in the other tube was more uniform and extended over a longer period, with a general slowing down observable after November 10. However, the mycelium in this tube was able to advance a distance of nearly 4 inches on the quantity of food supplied by the single small sclerotium alone. Under field conditions, a similar movement of the mycelium from a disconnected sclerotium might be the means of bringing the fungus to a fresh supply of food.

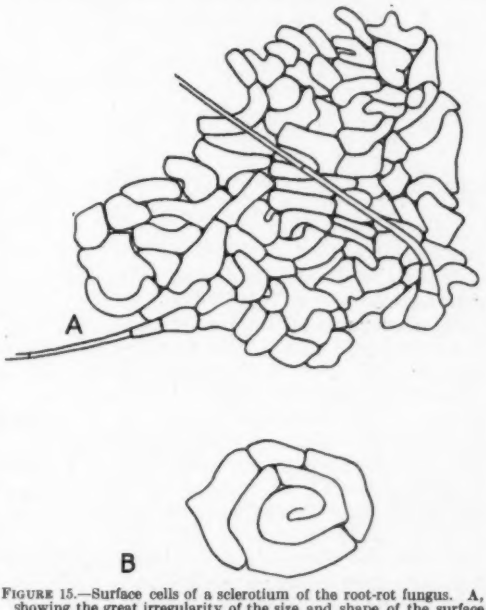

FIGURE 15.—Surface cells of a sclerotium of the root-rot fungus. A, showing the great irregularity of the size and shape of the surface cells and the development of the slender, acicular hyphae. × 350; B, series of cells with a somewhat spiral arrangement, of rather frequent occurrence on the surface of the sclerotia and largely responsible for its labyrinthine appearance. × 575

Although tests indicate that the sclerotia are very short-lived when removed from cultures and dried in the air before being placed on media, there is proof that they are capable of withstanding other rigorous treatments. A large number of sclerotia were surface sterilized by immersion in an aqueous solution of 1:1,000 parts of mercuric chloride for 30 to 60 seconds, after which they were rinsed in sterile water and placed on moist sterile cotton roots. Without exception, the mycelium began developing from the sclerotia within 24 hours. Sclerotia more than 45 days old and a few others 70 days old, all of which had been exposed in the culture jars to temperatures as low as 50° F., showed no loss of vitality after being removed from the jars and placed on a medium of moist cotton roots. Other sclerotia from these cultures were completely immersed in sterile water at room temperature for periods varying in length from 1 to 28 days. After being immersed for 28 days, four sclerotia were placed on cotton roots in culture tubes in the incubator and 18 hours later three of the four began developing hyphae which were easily visible to the eye. This ability of the sclerotia to live for long periods under

water may explain the survival of the root rot in areas that have been flooded for weeks or months in an effort to drown out the disease. Several instances of such persistence of the disease after flooding have been observed by the writers. In one instance water several inches deep was held continuously on a field in the Salt River Valley for 62 days during the winter, yet several spots of infection were noted in the cotton grown in this field the following summer.

TABLE 1.—*Daily growth of strands of Phymatotrichum omnivorum in glass tubes (3 feet long and 1 inch in diameter) filled with acid-washed sand and inoculated with a single true sclerotium on November 4, 1928*

Date	Growth		Date	Growth	
	Tube 1	Tube 2		Tube 1	Tube 2
	Mm.	*Mm.*		*Mm.*	*Mm.*
November 6		13	November 14	10	8
7	25		15	8	6
8		19	16	2	4
9	5	14	17		5
10		12	18		2
11		5			
12		6	Total growth	58	98
13	8	4			

Since the discovery of the sclerotia, many specimens have been used to establish cultures of the root-rot fungus, and their superiority over other parts of the fungus for this purpose has been demonstrated in several particulars. The fungus may be established in practically 100 per cent of the cultures inoculated with sclerotia, a much greater proportion than the writers have been able to obtain by any other means. The incipient growth of the mycelium on the nutrient medium takes place much more rapidly from sclerotia than from other parts of the fungus. A better opportunity is afforded for excluding contaminations from the cultures, as the surface of the sclerotia can be sterilized with antiseptic solutions before they are placed on the nutrient medium.

Efforts were made in several fields to find these sclerotia in the soil, but such efforts have been fruitless. There can be little doubt, however, that sclerotia occur in nature, although special requirements of food, moisture, and temperature may be necessary for their formation. From the evidence at hand it seems likely that they develop about the time the disease ceases to be destructive, with the approach of cold weather in the fall. The disappointing results that have been obtained in many places with chemical and cultural methods of control suggest the presence of a resistant form of the fungus, such as these sclerotia, which doubtless are capable of withstanding more severe treatments than the mycelium. It seems not improbable that the sclerotia may be responsible for the overwintering of the disease, at least in some parts of the infected regions.

MEASURING THE GROWTH OF MYCELIAL STRANDS

Taubenhaus and Killough (*16*) state that "Texas root rot spreads underground from contact of infected roots," and that otherwise "we should find hundreds of plants dying all at once in a given spot." Peltier, King, and Samson (*13*) are not in agreement with this view

and point out that the spread of the disease is through the agency of the advance mycelial strands, which are "present in advance of the wilting plants, while the mycelium in the zone of wilted plants serves as a food reserve for the advancing strand hyphae." Although the writers have been aware from field observations and from studying exhumed root systems of affected plants at various stages of infection, that the preponderance of evidence tended to support the latter theory of advance by mycelial strands, it seemed desirable to study this phase of the problem in greater detail on account of its important bearing on the development of control measures.

It was known from laboratory experiments that the mycelium grew readily on sterilized cotton-plant tissues, regardless of whether they were fresh or old and badly decomposed, and that its strands showed a tendency to grow in all directions from its food supply where moisture was afforded. An illustration of this tendency was furnished by a pure culture on a small piece of dead cotton root in a covered Petri dish kept in a 10-inch moist chamber on a large sheet of moist blotting paper on top of a laboratory worktable. After preparation, the culture was given no attention for several days. Then it was observed that the mycelium had escaped from the Petri dish, had grown several inches across the filter paper covering the bottom of the moist chamber, had climbed over the 2½-inch side of the lower section of the chamber, and had spread in its characteristic manner for 4 or 5 inches over the large sheet of moist blotting paper. After witnessing this and similar behavior, and after demonstrating that the strands grew readily from one end to the other of columns of moist sand or soil in student-lamp chimneys, the writers resorted to glass tubes 1 inch in diameter and from 30 to 36 inches in length for studying the elongation of the mycelial strands.

Satisfactory sterilization of these glass tubes was accomplished by filling them with alcohol and allowing this to remain for a few minutes before removal. They were then dried, flamed, and filled with the sterile soil or sand. After trial of various types of soil, it was found that the mycelial strands grew most rapidly in pure sand and were observed therein more easily than in soils of finer texture. Greater ease of preparing the glass-tube cultures also attended the use of sand, as the tubes could be filled to a more uniform density than was possible with moist soil, and the optimum moisture content could be more easily maintained. The sand was thoroughly sterilized in an autoclave before being placed in the tubes, and after the tubes were filled the moisture content was adjusted by standing the tubes upright and pouring sterile water in the upper end, allowing the excess to drain out below. After this the tubes were kept in a horizontal position, and the movement of water in the sand was negligible and offered no complications. When the correct moisture content was reached a section of cotton root covered with active strands from a pure culture was placed in one end of the tube which was then stoppered with a sterile cork. Several days usually were required before the mycelium began to grow through the sand and along the sides of the tube, where it could be observed easily by the use of a hand lens. The daily progress of the fungus along the tube was marked on the glass with a china-marking pencil, and the growth was thus measured and recorded.

The daily growth of the mycelial strands in the long glass tubes filled with sand, the treatments that the sand had received, and the

dates of the observations are shown in Table 2. Tubes 1 and 2 were filled with water-washed sand and were inoculated on August 23 with pieces of dead cotton roots, about ¼ by 1½ inches long, covered with a pure culture of *Phymatotrichum omnivorum*. The first elongation of the strands in tube 1 was observed on August 28, and in tube 2 on August 27. The ensuing growth in tube 1 appears to have been somewhat erratic for the first week, but this was due mostly to the fact that part of the mycelial growth occurred in the sand and was not visible for accurate measurements. Tube 2 had a more uniform growth of the fungus until after September 8, and on this date the piece of cotton root was removed from the tube in an effort to ascertain whether the growth of the fungus would be affected. Two days after the removal of the cotton root the elongation of the strands appeared to slacken, but later it continued at nearly the same rate as before. Though a slowing up of the growth actually took place, a part of the irregularities in the measurements may be ascribed to the fact that at times the most advanced portion of the strands was obscured in the sand and could not be accurately traced. Later, the daily advance of the strands was more easily discernible, and the growth continued at a rate nearly uniform and but little less than that in the control (tube 1) where the food supply

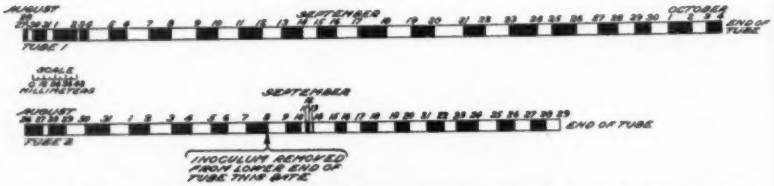

FIGURE 16.—Daily growth of the root-rot strands in long glass tubes, 1 inch in diameter, filled with water-washed sand and inoculated with the fungus on pieces of infected dead cotton roots at the lower end of the tube. In tube 1 the strands grew a distance of 764 millimeters and were stopped by reaching the end of the tube. In tube 2 the strands reached the end of the tube after growing a distance of 584 millimeters, of which 319 millimeters took place after September 8, after the piece of infected cotton root which was used to establish the fungus was removed from the tube

was not removed. The growth of the fungus continued through the whole length of the tubes, 30 inches in tube 1 and 23 inches in tube 2. In tube 2 the mycelium grew more than 12 inches after the removal of the piece of cotton root which served as a food supply to the fungus while establishing itself in the tube. The daily growth of the mycelium in these tubes is graphically shown in Figure 16.

In considering the behavior of the fungus in tube 2 after the removal of its original food supply, the idea was suggested that the sand in which the fungus was growing might contain organic matter which continued to furnish nutriment to the fungus after the removal of the cotton root. In order to determine whether such was the case, a quantity of sand was screened and immersed in a strong solution of sulphuric acid for two and one-half hours to remove the organic matter. It was then washed, sterilized by steam heat, placed in the tubes, and inoculated with the fungus on cotton roots in the same manner as was described for tubes 1 and 2. After the strands had advanced several inches through the sand the cotton roots were removed from some of the tubes, but in no case was growth stopped or more than slightly retarded.

TABLE 2.—*Daily growth of strands of Phymatotrichum omnivorum in glass tubes 1 to 6 (each 3 feet long and 1 inch in diameter) filled with sand, and inoculated with the fungus on pieces of dead cotton roots in 1928*

Date	Growth in sand washed in water		Date	Growth in sand washed in H_2SO_4		Date	Growth in sand washed in H_2SO_4, tube 5	Date	Growth in sand washed in H_2SO_4, tube 6
	Tube 1	Tube 2		Tube 3	Tube 4				
	Mm.	*Mm.*		*Mm.*	*Mm.*		*Mm.*		*Mm.*
Aug. 27		20	Sept. 21	12		Oct. 6	6	Oct. 30	13
28	5	7	22	26	14	7	11	31	13
29		18	23	16	18	8	8	Nov. 1	21
30	6	21	24	34	29	9	10	2	14
31	14	25	25	24	24	10	11	3	26
Sept. 1	8	23	26	21	15	11	14	4	25
2	26	22	27	22	23	12	18	5	21
3	3	24	28	15	17	13	14	6	20
4	8	21	29	20	[a] 16	14	12	7	28
5	23	22	30	28	25	15	9	8	23
6	20	18	Oct. 1	22	20	16	9	9	33
7	25	22	2	22	24	17	10	10	28
8	23	[a] 22	3	18	17	18	5	11	25
9	28	21	4	18	17	19	4	12	33
10	23	15	5	16	14	20	5	13	27
11	24	7	6	12	18	21	3	14	26
12	25	4	7	18	16	22	8	15	25
13	22	3	8	14	7	23	11	16	27
14	23	1	9	11	13	24	2	17	20
15	16	23	10	12	18	25	12	18	5
16	19	12	11	15	16	26	8	19	11
17	24	16	12	11	11	27	10	20	20
18	32	17	13	8	10	28	10	21	15
19	28	20	14	4	5	29	18	22	22
20	25	16	15	3	3	30	23	23	35
21	32	19	16	2	3	31	16	24	20
22	22	18	17	[b]	2	Nov. 1	14	25	32
23	27	15	18		1	2	14	26	21
24	31	22	19	4	3	3	13	27	25
25	16	21	20	[b]	4	4	14	28	30
26	27	19	21		6	5	15	29	30
27	23	18	22		6	6	19	30	15
28	21	17	23		3	7	19	Dec. 1	19
29	20	15	24		3	8	16	2	20
30	17	[c]	25		[b]	9	17	3	20
Oct. 1	21					10	14	4	24
2	23					11	19	5	15
3	17					12	23	6	13
4	17					13	8	7	10
5	[c]					14	17	8	10
						15	10		[c]
						16	4		
						17	3		
						18	2		
						19			
						20	2		
							[b]		
Total growth	764	584		428	421		510		860

[a] The piece of cotton root which supplied the food to the fungus in establishing itself in the tube was removed after the growth was recorded on this day.
[b] Growth ceased.
[c] End of tube.

The daily growth of the fungous filaments through the acid-washed sand in tubes 3 and 4 is shown in Table 2. In tube 4 the cotton-root plug was removed eight days after growth began, whereas in tube 3 the cotton-root plug was left, as a control. As will be seen in this table, or by reference to Figure 17, which illustrates graphically the progress of the strands in the tubes, the growth of the fungus was remarkably even in both tubes throughout the period of activity, with no retarding effect observable following the removal of the piece of cotton root from tube 4, as had occurred in tube 2. The terminal growth in the two tubes, as shown in Figure 17, was arbitrarily equalized on September 29, the day on which the cotton root was

removed from tube 4. The daily growth rate of the strands thereafter is seen to have been almost identical in the two tubes, the growth in tube 3 leading that in the other tube very slightly until October 13, when the growth in tube 4 caught up with that in tube 3 and thereafter exceeded it, both in the rate of elongation of the strands and the period of its activity. Late in October a period of low temperatures retarded and finally stopped the growth of the fungus in these tubes.

The most satisfactory explanation that seems to be offered for the continuation of growth of the strands in the tubes after the removal of the pieces of cotton roots is that it is a habit of the fungus to translocate nutrients rapidly from the older portions of the strands for the development of peripheral growth.

In another tube (No. 5 in Table 2) elongation of the strands was maintained for 46 days. This tube, which contained acid-treated sand, was inoculated on October 3. The first growth was detected on October 6, and continued until November 20. From October 6 to October 24 the tube was kept at ordinary room temperature, which, toward the end of this period, occasionally fell below 65° F. at night and caused a decided retardation of growth. On October 24 the

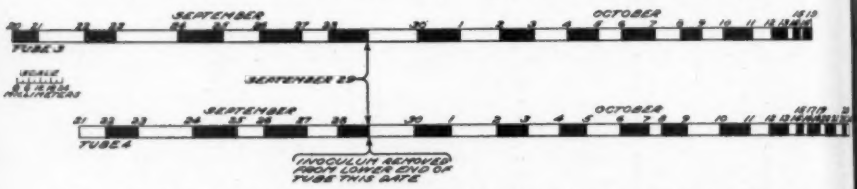

FIGURE 17.—Daily growth of root-rot strands in long glass tubes, 1 inch in diameter, filled with moist sand washed with strong sulphuric acid to remove the organic matter, and inoculated with the fungus on pieces of infected dead cotton roots at the lower end of the tubes. In tube 3, used as a control, the growth of the strands was both rapid and sustained until late in October. The infected cotton-root section was removed from tube 4 following the measurement of growth of the strands on September 29. It will be observed that no effect on the elongation of the strands is apparent after the removal of the original food supply

tube was placed in a thermostat-controlled incubator with a constant temperature of 25° C. An increase in the growth rate immediately took place and was maintained for three weeks, after which the growth began to slacken, and it stopped on November 20.

Another tube of acid-washed sand, here designated as tube 6, was inoculated on October 26 and was immediately placed in the incubator. The first growth of mycelium was noted on October 30, and this continued until the other end of the tube was reached on December 8. The daily increase in growth is shown in Table 2. With the exception of a short interval beginning November 18, a very uniform growth was maintained to near the end of the tube, where it was retarded, apparently by a somewhat drier condition of the sand. On several days the advance of mycelium through the tube exceeded 1 inch. In only one other instance was a greater advance made in a single day, a growth of 42 millimeters having been recorded in another tube in a previous experiment. The mycelium in tube 6 advanced a total distance of 860 millimeters, or approximately 34 inches, from the piece of cotton root which supplied food to the fungus and which was not removed from the tube.

REACTIONS WITH OTHER FUNGI

An exception to the continuously uniform elongation of the mycelium in tube 6 occurred between November 17 and 21, when the growth on one of these days decreased to 5 millimeters. This slowing down of growth occurred at a point about midway in the tube where a contamination in the form of a fungus which resembled a species of Fusarium pervaded the same column for a little over 2 inches of the length of the tube. The root-rot mycelium reached this contamination some time prior to the measurement of growth on November 17, but the maximum inhibitory action was apparent the following day and continued somewhat in effect for several days. However, after the contamination was passed the root-rot mycelium resumed growth at practically the same rate as before the secondary organism was reached.

Many cases of the inhibitory action of other fungi or of bacteria in cultures of *Phymatotrichum omnivorum* have been observed. Frequently the presence of another fungus in the long glass tubes containing sand, or in culture tubes, entirely checked the development of the root-rot mycelium, and in agar cultures the presence of colonies of bacteria retarded or entirely stopped the development of Phymatotrichum. This inhibitory action of specific fungi or bacteria suggests that other soil organisms may be a factor in the distribution of the disease and may account somewhat for the slow reinvasion of areas through which the disease has recently passed. It is commonly observed that root-rot injuries are generally followed by the appearance of other fungi, not capable in themselves of gaining entrance to living plants, and the activities of other fungi may hinder the immediate return of the root-rot fungus or discourage retrogressive movement of the strands.

EFFECTS OF VARIOUS PLANT TISSUES AND FLUIDS ON THE GROWTH OF ROOT-ROT MYCELIUM

The experiments with long glass tubes also made possible a preliminary study of the selective feeding of the fungus, as shown by the behavior of the strands visible in the tubes. A few tubes were filled with soil containing sterilized macerated roots of cotton, pomegranate, and citrus, and other tubes with soil moistened with sterilized sap that had been expressed from the leaves of the same plants. No growth of the fungus resulted from inoculations of the cultures containing the citrus and pomegranate products. However, the fungus did not fail to grow in any of the tubes containing macerated cotton roots, and it grew in one of the two tubes containing fluids of cotton-leaf tissue. The mycelium developed in these cultures was normal, and the elongation of the strands continued for a long period. Though the number of tubes included in this test was too small to give reliable information, the lack of growth of the fungus in the tubes containing citrus material is of interest in view of the results already mentioned in using citrus roots as culture media.

The uniform rate of elongation of the mycelial strands, when the fungus is cultured in columns of sand and maintained under similar conditions, affords an opportunity to study, with very simple equipment, the influence of various factors which may affect the growth of the fungus. The effect of temperature, moisture, chemicals, various plant tissues and fluids, competitive organisms, and other factors can be determined readily by this means.

OBSERVATIONS ON ROOT-ROT DISSEMINATION

The claim has been made by some investigators that root rot is spread from one field to another through fragments of fungus threads which are carried with soil particles by wind, or by the tools used in tillage, and by birds and animals. Warnings have been issued in regard to transferring soil from one field to another in inoculating for certain legume crops, and in the matter of distributing manures as fertilizers. Taubenhaus and Killough (*16*) are doubtful about the disease being spread by such methods as the above, but state that "it is safe to assume that the conidia, at least in the summer, do help to spread about the causal organism." The writers have never been able to obtain growth from detached fragments of strands from the soil, nor from those entirely separated from the surface of infected roots. Although attempts have been made by several investigators to germinate the conidial spores, there is as yet no record of a viable mycelium having been developed from them. On the basis of these facts and from observations made on infections in new areas and revived infection in old areas, it does not appear that the conidia play any important part in the dissemination of the disease. Nor is it believed that detached fragments of ordinary strands are a source of danger. There is, however, evidence to indicate that the disease can be transmitted to new areas on the roots of living plants, which may be susceptible to the disease or may serve only as carriers. Since there is good evidence that fragments of dead plant tissues harbor the mycelium in a viable condition, such tissues may be capable of conveying and transmitting the disease to new areas.

Although there is as yet no direct proof that the true sclerotia, as now shown to be developed in cultures, are produced under natural conditions in the soil, it is entirely reasonable to assume that they are, and this opinion may be supported by observations of the occurrence and dissemination of the disease. In preparations for growing ornamental plants about a pretentious winter home located on a rocky eminence near Superior, Ariz., a fertile soil was transported from the floor of a small stream bed which lay in a deep canyon at the rear of the residence. The fertile soil was placed in protected coves and depressions near the buildings. Many of the annuals planted in this soil were killed by the root-rot disease, which has persisted in these locations for several years. Plantings made later along the stream bed from which the soil was taken showed extensive root-rot infection.

Before the discovery of the sclerotial stage, the writers made several attempts to transmit the disease to new areas by transferring soil from infected areas, but all resulted in failure. These transfers were made during the summer months, with the precaution of taking the soil from the peripheral zone where the fungus was active. But from observations made in the laboratory it appears that the sclerotia may not be developed until late in the season, with the approach of winter.[4] If this also is true in nature, soil samples obtained in the summer from recently infected areas might contain only mycelium, whereas winter samples of soil might carry sclerotia.

[4] Subsequent experiments have shown that sclerotia may develop in cultures at any period of the year and under a wide range of temperature.

It may be true also that the development of sclerotia on old strands that remain in the soil for some time after the disease has passed would be interfered with to some extent by the activities of secondary organisms, and that the most extensive development of sclerotia would take place in the fall on the advance strands that are active on the edges of infected spots. This is indicated by the regularity with which the disease reappears in the spring on the margins of areas where the activity was last apparent. (Fig. 7.)

McNamara and Hooton [5] report having observed in 1926 a formation of spore mats in a large root-rot spot in a cotton field in close arrangement within the area that had been infected by the disease in 1923, while only a few mats were found in the area covered by the advance of the fungus during the subsequent five years. Apparently no one has been able to offer a satisfactory explanation for this phenomenal behavior, but with a knowledge of the sclerotia and their physiology, now available, explanations can be offered which are entirely reasonable, although still in the realm of conjecture.

In spite of failures that have been made in attempting to transmit the disease by transferring soil from infected areas, it is the opinion of the writers that practices which involve transfers of soil, such as the balling of trees for replanting, and releveling of land under irrigation, in infected places, involve the possibility of conveying the disease and establishing new infections.

Although several descriptions have been written in attempting to illustrate the manner in which the root-rot organism spreads through the soil and to define its relationship to its food supply, none of them, in the opinion of the writers, have succeeded in giving a complete or an entirely accurate account. This seems somewhat surprising in view of the fact that the mycological literature includes descriptions of several well-known fungi whose subterranean behavior is in many ways similar to that of *Phymatotrichum omnivorum*. One of the closest analogies is the destructive mushroom root-rot fungus (*Armillaria mellea*). This fungus leads a saprophytic existence on stumps and roots of dead trees, but under favorable conditions becomes a serious parasite. Although it frequently develops sporophores which produce basidiospores in enormous numbers, it also relies to a large extent on rhizomorphs for its dissemination. Massee (*10*) speaks of these cordlike rhizomorphs as being in reality elongate sclerotia which radiate in every direction in the soil, growing by the tips only. Heald (*4, p. 798, 801*) relates that they have an "apical growing region by the activity of which they advance through the soil or over the surface of the host. * * * The rhizomorphs spread in the soil from their original bases (on dead roots or stumps) to adjacent living hosts," etc. Although the strands or rhizomorphs of the cotton root-rot fungus are not so large and probably not so resistant to unfavorable conditions as those of the mushroom root-rot fungus, it is evident that they function in much the same manner. The behavior of the Phymatotrichum strands in cultures indicates that they are capable sometimes of developing a beadlike string of sclerotia throughout their length.

A study of the distribution of the root-rot mycelium through the soil in a favorable location in California furnished fairly definite proof

[5] McNamara, H. C., and Hooton, D. R. Op. cit.

that it is able to draw large quantities of nutritive material from dead root tissues in building up conidial mats or that it is able to accumulate in the soil for long periods. Mats appeared in enormous numbers in trenches at a considerable distance from any living host plants and where only dead tissues were in evidence in the soil. It was also apparent from the behavior in this location that the organism makes more rapid headway where plant roots or other food materials are abundant than where there is a scarcity of this material. Laboratory experiments have shown that the mycelium apparently does not derive suitable nutrients for sustaining growth from soil that contains no organic matter other than that which has been entirely broken down to the condition of humus, woods mold, muck, and peat.

All of these materials have been tried as food media in cultures without obtaining a satisfactory growth of mycelium. In the above-mentioned California location, where there is an infected area entirely isolated, there was evidence that the fungus had crossed bare roadways on two sides of an infected area and extended into new fields with the assistance of dead tree roots. In a field where cotton had been planted for about seven successive years, no infection was observed until 1927, when three plants were killed and about 60 neighboring plants showed infected roots. From this infection dead roots of an almond tree, covered with mycelial strands, were traced from the cotton to the opposite side of a roadway, though the trees were no longer in existence, as they succumbed to the disease and had been dug a year or two before. In another case the conducting tree roots had reached a more advanced stage of decay, but the disease had crossed a roadway to infect a date orchard, where no injuries to the palms above the ground were apparent.

The mycelium, however, had apparently received sufficient nourishment from the dead tree roots and from dead or living date roots to keep it alive and active, but the rate of progress had obviously been much slower where the quantities of deciduous tree roots diminished and the organism was made to rely more largely on date roots for nutrients.

As in the case of *Armillaria mellea*, the strands of Phymatotrichum are thus visualized radiating in all directions from a food-supply base, such as a plant root, and ramifying through the soil. When a susceptible plant root or other suitable food material, either of living or dead roots, is met by the advance strands, the mycelium accumulates around these as a new base, and as they afford a supply of food and provide for continued growth of the fungus, they are followed for long distances. In the case of a closely planted crop, such as alfalfa, there seems to be a tendency for the attack on the roots to be confined to the upper 2 or 3 feet, but on tree roots the strands have been found at a depth of 6 feet. Laboratory experiments have shown that the strands may extend for at least 34 inches through a soil that is inert and entirely devoid of nutrient material. In most soils a new supply of suitable food would probably be encountered in that distance to assist in further extension of the mycelium.

The rate at which the disease progresses by this underground method appears to be variable. On one area cropped to cotton continuously for many years it was noted that the disease in one isolated spot of infection advanced into uninfected territory a distance

of 53 feet in eight years. In an alfalfa field it was observed that a single circular spot of infection increased its diameter more than 60 feet in three years.

SUMMARY

Pure cultures of the cotton root-rot fungus *Phymatotrichum omnivorum* (Shear) Duggar, have been grown for periods of months on dead tissues of cotton and many other plants, and many successful inoculations of cotton plants have been obtained under partially controlled conditions by using these cultures. Hence it is plain that the root-rot organism is capable of living on dead plant tissues in the soil and can be communicated from these to susceptible plants. The facility with which plants can be inoculated from infected plant tissues, whether alive or dead, indicates that the transportation of such infected plant material may play a part in the dissemination of the disease.

The extensive distribution of the root-rot mycelium on the roots of certain monocotyledonous plants, such as date palm, Johnson grass, and Bermuda grass and the ability of the fungus to grow continuously for several months on the roots of these plants in cultures, indicate that the organism may be able to subsist on host plants of this type which would serve as carriers for the infection.

Certain plant roots are apparently better suited than others for nourishment of the root-rot fungus. On steam-cooked food, or alcohol-disinfected roots of some of the monocotyledonous plants such as date palm, grasses, corn, and barley, the fungus can be maintained for long periods, but the mycelium grows very slowly.

All attempts by the writers to culture the fungus on the fresh roots of citrus species have been unsuccessful, and from the manner in which the hyphae are inhibited in approaching these roots, it is apparent that the roots contain some material which interferes with the growth of the mycelium.

Cooked roots of some of the most susceptible plants, as cotton, Malva, and peach, provide a more favorable medium for the growth of the fungus than roots of some of those less susceptible, as cottonwood, tamarisk, jujube, and peppertree.

Live root-rot mycelium on decayed tree roots at a depth of 6 feet in the soil of some infected areas and the extensive development of conidial mats at this depth, in trenches, provide evidence that the organism is able to function throughout a large volume of soil and to considerable depths. For this reason difficulties of controlling the fungus by tillage or other methods which affect only the surface layer of soil are to be expected.

Barriers of oil mixed with soil, placed in narrow trenches about 3 feet deep, in front of the advancing line of infection were effective in checking the spread of the disease in alfalfa fields. Sheets of galvanized iron 26 to 36 inches wide, set on edge in trenches prepared in a similar manner, were equally effective.

A clean fallow maintained on two plots at Sacaton, Ariz., for two years had no effect in reducing the extent of the infection when the area was replanted to cotton. On an adjacent plot of the same size, fallowed for one year after a winter crop of peas had been turned under, no reduction in infection resulted from the treatment. When replanted to cotton after fallowing, the infected areas in all these plots were in nearly the same locations and maintained somewhat similar shapes and sizes as before.

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The large pseudosclerotial formations developed in artificial cultures are more elaborate structures than the small wartlike aggregates of hyphae found on infected roots in the soil, which also are considered as pseudosclerotia. For their most extensive development, suitable nutrients and an abundant moisture supply are required. Although these large mycelial masses are capable of preserving the life of the fungus for long periods under laboratory conditions, favorable conditions are required for them to remain viable, and they have not been found under natural conditions.

A true type of sclerotium formed from mycelial strands extending through sand and soil in pure cultures was discovered in September, 1928. These sclerotia appeared in great numbers in fruit jars and other containers in which sterile sand and dead cotton-plant tissues were present. Their production apparently is influenced by temperature conditions, but when fully developed they are capable of prompt germination, and show a vigorous growth of new mycelium under suitable temperature and moisture conditions.

The sclerotia are small round or oval tuberlike structures, attaining a diameter of 1 to 2 millimeters, of rather firm texture, showing in section rather large, closely packed cells, with one or more surface layers of smaller and harder cells of very irregular form. The structure of the sclerotia indicates that they are simple storage bodies that may serve for preserving the organism during periods of inactivity. They apparently are not injured by widely fluctuating temperature conditions, or by submergence in water for long periods, but do not seem to withstand desiccation in the air.

The hyphae which develop from the germination of the sclerotia consist of the large, Rhizoctonialike cells, which characterize a new growth of mycelium in this fungus. These in a short time begin the formation of strands which spread over the substratum in a characteristic manner.

The sclerotia provide a convenient means of propagating the fungus in the laboratory, since under the ordinary conditions of culture they give assurance of immediate and rapid mycelial growth, and contaminations are easily excluded because the sclerotia permit the use of antiseptic solutions on their surface tissues without injuring their viability.

Although the sclerotia have not as yet been found in nature, they doubtless occur under certain conditions, and may play an important rôle in maintaining the fungus through the winter. Also they may furnish an explanation of disappointing results with control measures in various places.

The indications that sclerotia may be formed in great numbers in the soil at certain periods of the year make it unsafe to assume that the disease can not be transmitted in soil from infected areas.

A method was devised for studying the elongation of the strands by establishing a pure culture of the fungus on small sections of dead cotton root in one end of long glass tubes containing sterile moist sand and measuring the daily growth of the strands. By this simple method the fact was established that the mycelial strands are capable of extending long distances from their food supply. Growth in one tube was continued for 46 days, the mycelium being nourished only by a small piece of dead tissue of a cotton plant.

In many of the tubes the strands of the fungus grew through a column of acid-treated sand a distance of 2 feet or more from the food supply. In one of the tubes a vigorous growth of the fungus was continued for 34 inches, when the end of the tube was reached.

In several of the tube cultures the plant tissues on which the fungus had been introduced were removed after a few days, and this was found to have little effect in retarding the growth of the strands. It appeared from these experiments that the fungus is capable of translocating nutrients from the older portions of its system for producing new apical growth.

The opportunity which the sand-tube cultures afford for observing and measuring the elongation of the strands renders this method applicable for studying the effect of various environmental factors on the growth of the fungus.

The presence of secondary organisms in cultures of the root-rot fungus retarded the growth of the mycelium and in some cases checked it completely. Under natural conditions the effects of other soil organisms upon the fungus may determine the distribution of the disease.

The fungus grows through the soil by means of its mycelial strands for considerable distances, and thus is capable of moving from one food supply to another. Though the spread of the disease into new areas by this means is apparently slow, more rapid progress may be made where the soil is pervaded with roots, so that a more continuous food supply is available.

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CORRELATION STUDIES WITH INBRED AND CROSSBRED STRAINS OF MAIZE[1]

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INTRODUCTION

The final test of every inbred line of maize is the ability of its crosses to produce large yields of sound corn. An extensive program of selection within selfed lines involves much labor and expense. Good lines could be produced more cheaply, and more rapid progress could be made if it were possible to recognize and discard in the earlier years of selfing those lines that are likely to give unproductive crosses. The studies herein reported were undertaken primarily to determine characters associated with productivity in the hope that these characters might then be used as indexes for selection.

The problem has been developed along three main lines. Coefficients of correlation have been computed (1) among a number of different characters in the same generation (*a*) within inbred lines and (*b*) within F_1 crosses, (2) between characters in the inbred parent lines and the same characters in the crossbred progenies, and (3) between the various characters of the inbred parent lines and the yield of the crossbred progenies. The correlations within lines or crosses (1) are of interest in indicating the characters within the crop itself which are associated with productivity. The parent-progeny correlations (2) indicate the extent to which the parental characters are expressed in the crosses, and (3) they indicate the degree to which characters of the parents influence productivity in the crosses. The parent-progeny correlations, therefore, are the most valuable as guides for selection.

Detailed data are presented on a number of characters of the parent lines and of their F_1 crosses in order to bring out some interesting relations in regard to differences in prepotency among inbred lines of corn. These relations are not brought out by the coefficients of correlation.

REVIEW OF LITERATURE

The extensive studies that have been reported on the relation between various characters and yield in open-pollinated corn need not be considered here. Because of the open-pollinated condition, they have no direct bearing on the present investigations. More recently several investigators have reported on the correlation of characters in inbred lines and their crosses.

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[2] The writer wishes to acknowledge his indebtedness to Dr. E. W. Lindstrom and F. D. Richey for their kindly criticism and many helpful suggestions during the progress of these investigations, to Prof. G. W. Snedecor and A. E. Brandt for many suggestions in regard to the mathematical phases of the problem, and to A. A. Bryan for very valuable assistance during the selection of the inbred lines and the making of the F_1 crosses.

Kiesselbach (*5*)[3] found a general relation between the productivity of inbred parents and that of their hybrid offspring. Exceptions to this general rule, however, were noted.

Richey (*8*) found that the tendency of certain strains to produce high-yielding crosses was very noticeable. For example, the mean yield of the seven crosses involving a certain strain exceeded the yield of any single one of the remaining 34 crosses not involving this strain. In later experiments with the same material Richey and Mayer (*10*) found that some inbred lines were much superior to others in producing high-yielding crossbred combinations.

Kyle and Stoneberg (*6*) noted that inbred lines having smaller numbers of kernel rows had a greater length of ear per plant, were more resistant to corn smut, had fewer plants with certain heritable deleterious characters, and were generally more vigorous and productive than the lines having larger numbers of kernel rows.

Hayes (*2*) presented a number of coefficients of correlation to show the inheritance of various characters through different generations of inbreeding. In general, these correlations were positive, as would be expected. The larger coefficients were obtained for length of ear, size of seed, and cob discoloration, although, for some varieties, percentage of smut infection and lodging were rather strongly correlated in the different selfed generations. A number of coefficients of correlation between yield of the inbred lines and various other characters also were given. Yield was found to be strongly correlated with other characters of the inbred lines which are expressions of vigor.

More recently, Nilsson-Leissner (*7*), in experiments conducted in Minnesota, found that some inbred lines were distinctly superior to others as parents of crosses. He reported the yields of most of the possible combinations among 13 dent inbreds and among 9 flint inbreds. Both among the dents and among the flints certain inbred lines produced higher yielding F_1 crosses. Coefficients of correlation between certain characters in the selfed lines and the same characters in F_1 crosses also were reported. The correlations were positive in every case. Correlations between the yield of the F_1 cross and the mean yield of the two parental lines were 0.1852 ± 0.0580 in the group of dent inbreds, and 0.7434 ± 0.0427 in the group of flint inbreds. Multiple correlations between yields of the F_1 crosses and five characters in the parental lines were 0.6687 in the dents and 0.8240 in the flints.

Jorgenson and Brewbaker (*4*), in experiments also conducted in Minnesota, obtained data on 10 inbred lines from the dent variety Silver King and on the F_1 crosses between them. Both high and low yielders were found among the crosses from each inbred line. On the basis of the average yield of all of the F_1 crosses in which they were used as parents, some inbred lines appear distinctly superior to others. These investigators also report a number of correlations between various characters in the F_1 crosses and the mean value of the same characters in the two parental lines. Their coefficients of correlation, like those of Nilsson-Leissner (*7*), are all positive. They calculated a multiple correlation with yield of the F_1 cross as the dependent variable and length of ear, diameter of ear, number of

[3] Reference is made by number (italic) to "Literature cited," p. 721.

kernel rows per ear, height of plants, and yield in grams per hill of the parent lines as the independent variables. This correlation was 0.6074. The highest simple correlation with yield of the F_1 cross was that of 0.5000 ± 0.0771 with yield of grain in the parents.

MATERIAL

The inbred lines used in these experiments are listed in Tables 1 and 2. These tables show the pedigree number of each line, the variety from which it originated, and a summary of the data on its F_1 crosses. The lines are entered in the tables in the order of their occurrence in the crossing blocks. The crossing-block row numbers are used to designate the lines in other parts of the paper. Most of the inbred lines were produced at Ames, Iowa, during the progress of these investigations. Five inbred lines (Nos. 41, 42, 174, 175, and 176) were obtained from J. R. Holbert, of the Office of Cereal Crops and Diseases, United States Department of Agriculture, Bloomington, Ill., and one inbred line (No. 112) was obtained from E. W. Lindstrom, of the department of genetics, Iowa State College.

Most of the inbred lines listed in Tables 1 and 2 were used both in the correlation studies within inbred lines and in the parent-progeny correlations. There were a few exceptions, however, which are indicated in the tables. In the computation of the coefficients of correlation within inbred lines data were included on 10 lines not used in crosses. Naturally these lines had to be omitted from the parent-progeny correlations. Conversely, in the computation of the correlations within F_1 crosses data were included on the crosses of 12 parent lines for which no data were available on the inbred lines themselves. In the parent-progeny correlations these crosses could be paired only with the one parent for which data were available.

TABLE 1.—*Crossing-block row numbers, pedigree numbers, parent varieties, and the means for the different characters in all of the crossbred progeny of each inbred parent line of corn in 1924*

Color group and crossing-block row No.	Pedigree No.	Parent variety	Means for the different characters in the crossbred progeny of each inbred line																			
			Number of crosses averaged	Date of—[a]		Shrinkage of harvested ears	Plant height	Number of nodes		Nodes below ear	Plants smutted	Plants erect at harvest	Ears moldy	Suckers per 100 plants	Plants with 2 or more ears	Ears per plant	Ear length	Ear diameter	Ear-shape index (diameter÷length)	Mean number of kernel rows per ear	Shelling percentage	Yield per row
				Tasseling	Silking			Per plant	Below ear													
White corn:						*Per cent*	*Feet*			*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Number*	*Per cent*	*Number*	*Cm.*	*Cm.*				*Lbs.*
1[b]	5-3-1-1	Four-County White	10	18.4	22.0	26.4	6.90	13.4	7.9	59.0	2.5	76.6	11.2	6.5	1.1	1.019	16.2	4.58	0.282	16.0	84.6	12.07
2	13-1-4-2	do	10	20.6	22.4	25.0	6.60	14.0	8.2	58.3	8.8	39.2	21.2	2.4	1.3	.989	18.9	4.54	.242	14.8	86.5	13.44
3	20-5-1-2	do	10	16.0	19.2	22.2	6.95	12.2	6.8	55.5	1.8	77.6	18.7	3.1	1.8	1.009	16.5	4.38	.267	14.2	85.3	11.19
4	27-1-2-4	do	10	17.6	22.0	24.5	7.00	12.8	7.8	60.5	6.5	60.7	18.8	2.7	1.7	1.000	18.0	4.55	.254	14.4	86.2	13.02
5	36-1-4-2	do	10	17.1	19.2	24.2	6.90	12.8	7.4	57.9	5.0	34.2	17.8	2.5	1.4	.980	15.9	4.64	.293	14.2	87.7	12.53
6	63-4-3-5	do	10	18.1	20.4	23.2	6.95	13.3	7.8	58.9	2.1	82.6	14.8	4.8	1.0	1.007	17.3	4.60	.267	14.5	85.0	12.78
7	82-1-1-5	do	10	17.5	19.4	20.5	7.00	13.0	7.8	60.2	1.7	75.6	13.2	4.7	1.8	1.030	17.6	4.66	.265	15.2	85.9	13.24
9	111-4-5-5	Silver King	10	17.1	19.2	21.5	7.20	13.0	7.4	56.5	1.4	35.2	12.2	3.9	3.0	1.028	17.7	4.44	.252	14.1	87.4	13.80
10	122-2-3-4	do	10	16.5	19.0	23.9	6.70	12.6	7.2	56.9	2.8	65.9	17.4	8.3	1.2	1.010	16.3	4.61	.285	14.4	86.1	11.84
11	10-4-2-1	Four-County White	9	16.4	19.4	23.4	6.90	13.2	7.6	57.1	2.2	55.5	14.5	3.4	1.3	.994	16.3	4.46	.274	14.8	86.0	11.25
12	16-1-4-1	do	9	16.9	19.5	20.2	6.65	12.6	7.2	57.5	3.1	59.9	10.3	5.6	1.6	1.041	16.7	4.62	.281	14.2	86.7	12.88
13[b]	24-3-1-6	do	9	17.0	19.2	23.3	6.95	12.4	7.6	60.8	1.0	69.4	8.7	1.8	.6	.972	17.6	4.49	.257	14.9	84.3	11.96
14	31-5-5-2	do	9	15.7	18.6	22.7	7.10	12.7	7.0	55.3	.9	84.7	9.2	3.1	.3	1.022	17.0	4.73	.279	15.6	88.3	14.63
15	40-1-2-1	do	9	17.1	20.2	21.3	6.90	13.0	7.7	58.9	2.8	28.2	18.0	4.3	2.0	1.033	17.4	4.62	.267	14.9	86.6	13.52
16	74-5-5-4	do	9	16.0	18.1	20.6	7.10	13.0	7.6	58.3	1.1	73.9	14.4	2.8	.5	.974	15.9	4.52	.285	14.3	86.0	12.03
17	87-3-2-1	do	9	17.2	19.8	24.2	6.80	12.5	7.4	59.0	.5	80.2	6.4	4.6	1.2	1.000	16.4	4.72	.288	16.2	87.1	12.69
18	107-4-4-1	do	9	18.9	20.7	25.2	6.60	13.5	8.0	59.1	8.1	37.9	36.4	6.3	2.5	1.013	17.2	4.53	.266	14.6	86.5	12.12
19	115-3-2-3	Silver King	9	17.0	19.9	24.1	6.85	12.8	7.2	56.7	9.2	66.4	27.1	4.4	1.7	1.015	17.8	4.39	.248	13.6	85.3	12.09
20[b]	497-3-4-1	Western Flint	9	24.4	26.8	29.9	7.20	14.4	8.6	59.4	7.5	52.2	16.5	6.9	4.2	1.016	19.5	4.48	.231	13.4	83.9	13.40
Mean				17.7	20.2	23.5	6.91	13.0	7.6	58.2	3.6	60.8	16.1	4.3	1.6	1.008	17.2	4.55	.267	14.6	86.1	12.66
Early yellow:																						
21	129-4-2-4	C. I. 133	10	17.4	19.6	24.2	7.5	13.9	8.0	57.4	15.1	43.0	27.9	5.5	2.7	.928	15.9	4.24	.270	14.1	83.8	9.10
22	147-3-4-1	do	10	18.0	21.0	24.0	7.2	13.4	8.2	60.9	17.8	68.6	14.8	6.5	3.9	1.036	16.6	4.36	.264	14.4	85.8	11.50
24	280-3-6-1	C. I. 204	10	20.3	24.6	27.4	7.2	13.1	7.8	59.2	1.8	63.9	10.7	7.2	1.6	1.052	17.0	4.76	.279	16.8	84.9	12.41
25	420-2-7-6	Osterland's Reid	10	20.8	23.5	27.3	7.2	13.4	8.0	59.2	1.7	88.0	8.6	6.4	2.3	1.053	18.6	4.61	.250	15.6	85.3	14.05

26	426-5-2-4	do	10	21.8	24.4	23.8	7.2	13.8	8.0	58.4	4.6	58.2	5.3	17.5	3.0	1.081	18.2	4.55	.251	15.5	85.0	13.82
27	432-3-2-4	Clark Yellow Dent	10	17.2	20.8	24.0	6.9	12.8	7.6	59.4	2.6	82.2	12.1	5.2	3.1	1.051	15.0	4.27	.288	14.9	84.0	9.69
28	439-2-2-3	do	10	22.6	22.5	23.3	7.1	14.6	8.2	56.7	2.1	67.5	7.6	8.4	10.5	1.084	17.4	4.46	.258	15.0	86.6	12.40
29	472-1-1-1	Argentine Flint	10	21.6	23.0	29.3	7.2	13.9	7.8	56.0	2.9	57.1	6.0	27.3	6.1	1.143	17.1	4.30	.254	14.3	84.4	12.61
30	487-5-1-5	do	10	19.4	21.3	24.5	7.6	13.9	8.4	60.2	2.5	69.9	7.4	8.5	9.9	1.130	16.5	4.38	.267	13.9	85.3	12.88
31	140-3-3-2	C. I. 133	9	18.0	20.7	23.6	7.2	14.1	8.5	60.3	4.1	66.4	15.1	8.2	2.2	1.005	16.3	4.53	.278	14.2	85.3	12.30
32	150-3-3-3	do	9	18.2	22.1	23.7	6.9	12.9	7.5	58.0	2.7	65.9	9.9	3.8	2.3	1.012	15.0	4.46	.302	15.5	83.7	9.89
33	276-5-4-2	C. I. 204	9	20.0	22.5	28.1	6.8	12.8	7.5	58.6	2.0	59.0	12.2	4.5	.7	1.010	16.0	5.01	.315	17.7	85.3	12.92
34	282-2-4-6	do	9	22.8	25.1	25.5	7.2	14.0	8.1	58.0	5.2	69.6	16.3	6.0	2.2	1.025	16.9	4.57	.273	15.3	84.8	12.25
35	422-5-3-1	Osterland's Reid	9	19.4	21.7	25.0	7.3	13.1	7.8	59.4	4.4	72.0	6.2	15.7	2.3	1.032	19.2	4.33	.226	14.1	86.0	12.77
36	428-5-1-3	do	9	21.6	24.0	24.0	7.6	13.5	7.8	57.4	16.3	84.3	17.9	7.5	2.6	1.032	17.8	4.32	.243	15.0	85.7	12.40
37	436-1-3-1	Clark Yellow Dent	9	18.5	20.9	22.9	7.3	14.0	8.3	59.7	4.9	77.0	6.8	7.7	3.0	1.044	16.9	4.54	.269	15.7	85.5	12.49
38	443-4-2-6	do	9	19.1	20.8	24.1	7.6	14.6	7.8	53.6	4.7	61.3	11.0	6.5	1.9	1.022	16.1	4.50	.281	16.2	86.5	12.75
39	483-5-4-1	Argentine Flint	9	21.9	22.4	28.2	7.4	14.4	8.5	59.2	8.6	57.8	7.8	28.0	18.9	1.308	18.0	3.99	.223	13.2	83.2	12.10
40	493-3-1-5	do	9	19.4	22.7	28.1	7.2	13.1	8.1	62.0	3.9	51.7	8.3	15.1	11.7	1.126	17.4	4.11	.235	12.5	84.0	10.65
Mean				19.9	22.3	25.3	7.2	13.6	8.0	58.6	5.7	66.5	11.2	10.3	4.8	1.062	16.9	4.44	.265	14.9	85.0	12.05
Later yellow:																						
41 [b]	Holbert's A-1-1-R-4-J33-2.	Funk Bros. 176 A	29	25.3	26.2	23.9	6.86	14.2	8.0	56.2	2.9	84.1	9.0	9.8	.9	1.044	19.6	4.71	.242	16.9	86.2	14.26
41 [b]	Holbert's B-1-1-2-4-J2-6-15.	do	29	22.6	25.1	22.6	8.17	13.9	7.5	54.0	3.7	68.3	9.6	12.2	.4	1.055	19.1	4.76	.250	16.3	86.0	15.58
43	304-1-3-3	Lancaster Surecrop	29	26.1	27.9	23.4	8.02	14.7	8.4	56.8	1.3	58.1	18.1	13.3	1.2	1.044	21.0	4.74	.227	16.7	86.4	16.81
45	325-4-2-1	do	9	23.7	24.7	23.1	8.08	14.0	8.0	57.3	1.2	57.2	13.4	7.4	.7	1.036	22.8	4.71	.209	14.0	87.1	16.92
46	178-2-2-4	Iodent	10	24.2	25.2	22.9	8.45	13.8	7.6	54.7	2.0	87.6	9.0	14.3	3.2	1.069	20.7	4.74	.231	16.0	85.2	14.12
47	221-3-2-1	do	9	23.5	25.6	24.0	8.19	14.6	8.4	57.8	2.2	43.5	9.0	5.7	.1	1.018	20.0	4.69	.236	15.9	84.9	14.71
48	211-4-4-2	do	10	24.0	24.6	24.5	7.55	14.7	8.4	57.1	3.1	72.6	16.7	27.6	9.0	1.229	20.6	4.57	.224	14.9	86.3	15.98
49	244-5-3-1	do	10	24.2	24.6	23.0	8.15	14.8	8.4	56.9	2.6	88.6	9.1	7.4	.8	1.031	20.3	4.74	.235	15.2	86.2	16.94
50	173-3-3-3	do	28	25.6	26.8	22.4	8.01	15.0	8.3	55.2	1.3	78.8	8.2	12.2	.7	1.051	20.2	4.74	.235	16.2	84.6	15.26
51	218-4-4-8	do	10	24.6	26.3	22.5	8.48	15.3	8.6	56.2	3.0	69.6	10.5	12.3	1.1	1.046	19.8	4.90	.248	14.9	84.0	15.05
52	154-4-4-3	do	10	25.3	27.0	25.0	8.25	15.2	8.8	58.2	1.2	55.6	12.0	7.6	3.3	1.060	19.7	4.62	.236	16.4	85.0	14.87
53	159-1-4-4	do	24	24.5	26.3	24.4	8.07	14.7	8.5	57.7	5.1	81.4	6.3	33.4	1.7	1.157	18.8	4.74	.253	15.9	85.5	16.36
54	170-2-4-1	do	10	23.5	24.8	23.9	7.62	13.9	8.2	59.2	5.2	48.4	11.2	26.7	.3	1.094	19.7	4.63	.237	15.1	87.6	15.43
55	194-5-5-5	do	10	23.3	25.0	25.0	7.65	14.0	7.8	56.1	1.8	54.2	17.4	8.1	.4	1.035	18.8	4.90	.263	16.9	87.3	15.22
56	202-1-2-2	do	7	23.6	24.6	21.0	7.50	13.6	8.0	58.5	2.7	62.2	8.6	11.2	.2	1.042	19.5	4.75	.247	16.5	86.2	14.37
57	205-5-4-2	do	9	24.6	24.9	24.3	7.64	14.2	8.5	59.5	.9	92.3	9.3	7.4	1.2	1.063	19.1	4.93	.260	16.8	86.0	16.61
58	227-2-2-1	do	10	24.6	26.3	22.1	8.18	14.9	8.7	58.5	.4	48.6	7.1	5.6	1.3	1.035	19.3	4.74	.248	17.2	86.6	16.29
59	230-3-1-5	do	8	24.2	26.1	25.1	7.91	14.5	8.0	55.3	1.0	77.3	7.0	2.7	.3	1.009	20.6	4.77	.234	17.4	85.5	17.50
60	238-3-2-6	do	10	26.2	28.4	24.9	8.00	15.0	8.2	54.5	1.3	45.6	9.2	8.6	2.2	1.049	18.9	4.68	.249	17.4	85.8	16.38
61	245-4-4-2	do	10	26.6	28.0	22.6	7.90	15.6	8.5	54.5	1.7	48.2	8.1	13.2	2.2	1.064	21.4	4.55	.215	15.4	84.6	14.85
62	258-4-1-2	do	10	23.2	24.9	24.0	7.62	14.4	8.2	56.9	2.8	93.2	7.1	4.2	.3	1.006	17.9	4.86	.274	17.2	85.8	14.73
63	265-4-2-2	do	28	23.5	25.0	22.4	7.46	13.6	7.8	57.8	4.4	74.6	14.3	19.8	.7	1.059	17.6	4.81	.275	18.0	86.5	13.77
64	292-3-1-2	Lancaster Surecrop	28	24.0	26.5	26.4	8.37	14.2	8.1	56.8	1.6	59.8	9.2	8.7	2.9	1.083	22.1	4.61	.210	14.4	84.6	16.51
65	309-1-2-2	do	29	25.3	27.8	24.6	8.65	15.4	8.9	57.7	.6	48.0	11.3	4.9	1.1	1.012	22.6	4.66	.208	15.9	85.6	16.96
66	345-4-1-6	Black's Reid	10	25.5	27.4	24.2	8.12	16.0	9.4	58.6	1.8	67.9	15.6	26.6	2.6	1.142	19.0	4.72	.251	16.1	87.1	17.81
67	347-3-3-1	do	10	25.6	28.2	25.7	8.00	14.0	7.8	55.8	3.6	82.7	13.2	43.3	1.6	1.189	21.4	4.45	.210	15.6	85.6	14.12

[a] The dates of tasseling and of silking are recorded as the number of days after June 30.
[b] Used as the parents of crosses, but no data on the lines themselves were available for use in the correlation studies.

TABLE 1.—*Crossing-block row numbers, pedigree numbers, parent varieties, and the means for the different characters in all of the crossbred progeny of each inbred parent line of corn in 1924*—Continued

Color group and crossing-block row No.	Pedigree No.	Parent variety	Means for the different characters in the crossbred progeny of each inbred line																			
			Number of crosses averaged	Date of—[a]		Shrinkage of harvested ears	Plant height	Number of nodes		Nodes below ear	Plants smutted	Plants erect at harvest	Ears moldy	Suckers per 100 plants	Plants with 2 or more ears	Ears per plant	Ear length	Ear diameter	Ear-shape index (diameter÷length)	Mean number of kernel rows per ear	Shelling percentage	Yield per row
				Tasseling	Silking			Per plant	Below ear													
Later yellow:						*Per cent*	*Feet*			*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Number*	*Per cent*	*Number*	*Cm.*	*Cm.*				*Lbs.*
68	356-5-3-3	Black's Reid	10	23.2	26.8	25.9	7.75	13.9	8.0	57.4	5.2	87.4	7.6	9.7	.4	1.049	21.0	4.61	0.222	15.6	85.4	15.41
69	363-4-2-5	Proudfit's Reid	10	27.0	28.4	23.3	8.00	14.9	8.6	57.4	4.5	57.5	16.6	27.0	.5	1.086	19.5	4.98	.256	16.5	87.0	16.41
70	364-5-4-3	do	10	23.1	25.2	25.5	7.80	14.6	8.4	57.6	7.3	80.8	17.6	31.7	.4	1.064	19.4	4.80	.251	18.8	88.2	15.53
71	377-3-1-4	do	29	26.1	28.3	29.4	8.64	15.5	9.0	58.4	8.7	67.7	8.3	11.4	2.8	1.066	18.6	4.89	.264	17.2	87.1	15.70
72	385-5-6-2	Krizer Bros. Yellow Dent.	10	23.8	28.4	27.2	8.20	14.8	8.4	57.0	4.0	75.0	11.5	11.6	.2	1.026	18.8	5.02	.270	17.8	85.8	15.55
73	390-3-1-2	do	9	27.6	30.3	23.0	8.44	14.3	8.2	56.7	8.4	86.4	7.6	9.7	.6	1.009	18.7	4.94	.267	18.4	85.1	14.92
74	393-2-6-2	do	10	27.7	30.8	25.6	8.15	14.5	8.8	60.2	8.2	68.4	13.8	12.0	.9	1.079	20.2	4.68	.234	16.5	84.8	15.41
75	401-1-2-5	McCulloch's Reid	28	25.3	27.8	22.5	8.11	15.0	9.0	60.6	2.2	81.2	18.2	20.2	2.1	1.084	19.0	4.82	.254	16.4	88.1	16.19
76	405-3-2-1	do	10	25.7	28.8	23.8	7.92	14.6	8.6	59.0	.7	50.1	11.0	5.6	.1	1.016	18.7	4.77	.258	18.1	86.5	15.88
77	412-5-4-4	do	10	27.6	28.9	22.8	8.65	14.8	8.4	57.1	3.2	80.3	17.7	17.5	.8	1.056	20.0	5.04	.254	17.5	86.8	17.41
78	456-3-2-1	Walden Yellow Dent.	10	25.0	26.0	25.0	8.10	15.2	8.8	57.6	1.4	87.8	8.7	6.2	.9	1.023	20.9	4.56	.220	15.2	85.6	15.71
79[b]	461-2-1-1	do	10	26.2	30.0	25.5	8.68	14.7	8.0	54.2	8.8	76.4	9.2	27.7	4.7	1.161	20.4	4.71	.233	17.3	86.7	15.98
80	467-1-4-1	do	10	23.0	25.5	25.2	7.90	14.8	8.3	56.2	.9	74.0	11.4	8.8	1.1	1.032	19.6	4.66	.238	15.6	87.0	16.08
Mean				24.8	26.8	24.2	8.03	14.6	8.3	57.1	3.1	69.7	11.3	14.0	1.4	1.063	19.9	4.75	.242	16.4	86.1	15.73

[a] The dates of tasseling and of silking are recorded as the number of days after June 30.
[b] Used as the parents of crosses, but no data on the lines themselves were available for use in the correlation studies.

TABLE 2.—*Crossing-block row numbers, pedigree numbers, parent varieties, and the means for the different characters in all of the crossbred progeny of each inbred parent line of corn in 1926*

Color group and crossing block-row No.	Pedigree No.	Parent variety	Means for the different characters in the crossbred progeny of each inbred line								
			Crosses averaged	Date of—[a] Tasseling	Date of—[a] Silking	Shrinkage of the harvested ears	Plant height	Plants erect at harvest	Ear moldy	Shelling percentage	Yield per row
White corn:			*No.*			*P.ct.*	*Feet*	*P.ct.*	*P.ct.*		*Lbs.*
101	3-3-3-3-composite	Four-County White	10	25.1	28.4	11.1	6.8	95.0	4.8	86.4	11.08
102	11-4-1-3-composite	do	10	25.1	30.2	12.2	7.6	93.8	2.7	85.3	11.86
103	16-4-3-3-composite	do	10	22.9	27.0	11.7	6.8	91.7	4.3	86.4	11.20
104	29-3-5-4-composite	do	9	24.0	26.4	10.3	6.6	91.9	4.1	85.4	11.19
105	46-5-4-2-composite	do	9	25.8	30.0	11.9	6.9	97.2	2.5	84.1	11.23
106	56-3-3-4-composite	do	10	26.0	29.0	13.6	7.1	89.6	1.4	84.3	11.51
107	63-4-1-6-composite	do	10	24.6	28.1	12.4	7.3	93.3	.7	85.5	12.29
108[b]	67-4-2-1-composite	do									
109	80-1-3-6-composite	do	10	26.1	29.6	14.3	6.9	94.8	3.4	84.6	11.32
110	101-4-5-5-composite	do	10	25.5	28.6	12.7	7.3	94.2	3.0	84.4	12.09
111	128-1-3-2-composite	Silver King	9	24.8	27.5	11.9	7.3	86.1	6.2	84.7	11.42
112[c]	Lindstrom 7117-composite.	White Flint	9	25.7	29.5	13.7	7.4	86.7	1.6	85.6	12.35
113[b]	50-5-3-6-composite	Four-County White									
	Mean			25.0	28.6	12.4	7.1	92.3	3.1	85.1	11.60
Yellow corn:											
114	134-3-2-4-composite	C. I. 133	9	27.1	32.4	14.6	7.6	73.4	4.8	83.2	10.06
115[b]	135-4-5-6-composite	do									
116	153-5-2-2-composite	do	9	26.4	30.4	13.8	7.0	89.0	2.5	85.2	9.84
117	155-2-2-2-composite	Iodent	9	34.4	39.0	17.1	7.8	68.6	4.6	83.0	10.41
118	157-3-1-3-composite	do	9	34.5	38.4	17.7	7.8	74.0	2.1	82.5	10.31
119	161-1-3-3-composite	do	9	34.5	39.0	19.7	8.4	79.2	2.6	80.8	10.68
120	169-4-4-1-composite	do	9	34.4	39.4	13.8	8.0	49.7	3.8	83.0	11.08
121	170-2-3-2-composite	do	42	33.2	37.8	15.5	7.9	80.2	2.8	83.8	10.38
122[b]	183-4-5-2-composite	do									
123	188-1-4-1-composite	do	9	32.2	38.0	16.4	7.9	82.1	5.2	84.6	10.35
124	197-1-2-6-composite	do	9	32.6	35.7	17.3	8.1	85.0	2.5	83.5	12.30
125	207-2-5-2-composite	do	8	32.8	37.0	18.6	7.9	75.7	2.9	83.6	10.90
126	215-2-5-1-composite	do	9	33.4	38.1	15.9	8.4	80.1	1.3	84.2	11.85
127[b]	219-3-1-5-composite	do									
128	224-2-2-1-composite	do	9	34.6	38.4	15.2	8.2	86.6	1.8	84.0	11.72
129	234-2-3-1-composite	do	9	34.2	38.1	16.2	8.2	75.0	3.1	83.7	11.16
130	254-3-6-1-composite	do	9	36.5	40.7	20.1	8.3	66.3	6.3	83.8	10.91
131[b]	262-3-3-2-composite	do									
132	267-3-5-2-composite	do	9	34.6	39.2	15.8	8.0	77.6	1.9	83.4	11.13
133	275-3-5-1-composite	C. I. 204	9	34.9	39.4	17.6	7.8	72.1	3.9	84.1	9.85
134[b]	278-3-4-1-composite	do									
135	289-4-3-5-composite	Lancaster Surecrop	9	32.0	37.1	16.1	7.8	63.3	4.7	84.6	12.43
136	291-1-6-1-composite	do	9	33.6	38.4	17.3	8.0	45.3	1.3	83.2	11.65
137[b]	307-2-4-4-composite	do									
139	315-2-4-3-composite	do	9	32.4	37.6	18.7	8.0	50.2	2.7	82.3	11.39
140	317-3-1-2-composite	do	41	34.2	39.4	19.8	8.4	62.4	4.2	81.6	11.46
141	324-2-2-1-composite	do	9	32.4	37.7	19.6	7.8	61.5	9.5	82.5	11.17
142	331-3-1-7-composite	do	9	31.0	35.8	19.5	7.9	49.0	3.5	80.8	11.76
143	345-2-1-5-composite	Black's Reid	43	33.8	38.4	15.2	8.4	75.1	5.5	82.7	10.56
144	348-3-1-5-composite	do	9	33.8	38.7	16.2	7.9	61.4	1.4	82.0	10.98
145[b]	349-5-1-6-composite	do									
146	351-4-5-5-composite	do	9	33.7	38.1	17.1	8.2	71.4	3.7	84.8	12.27
147	353-5-1-1-composite	do	9	34.6	39.3	19.3	8.0	82.1	3.2	85.4	9.79
148[b]	358-2-6-2-composite	Proudfit's Reid									
149	365-4-3-1-composite	do	9	32.8	38.6	19.0	8.4	76.0	1.9	84.4	10.39
150	370-1-1-1-composite	do	43	33.6	38.9	18.4	7.6	68.6	3.1	84.8	10.57
151	389-5-2-1-composite	Krizer Bros. Yellow Dent.	7	34.8	38.2	19.7	7.8	41.4	1.8	85.1	10.16
152[b]	391-5-5-1-composite	do									
153	394-4-2-1-composite	do	43	32.0	36.1	17.6	7.6	82.7	2.5	84.1	10.79
154	397-1-2-1-composite	do	9	32.7	37.1	19.7	7.6	64.8	3.0	82.5	11.39
155	398-1-2-2-composite	McCulloch's Reid	9	33.4	37.7	17.6	8.2	78.5	6.9	83.4	11.19
156	399-1-1-6-composite	do	9	31.6	36.1	14.5	8.0	78.6	3.3	84.6	10.49
157	411-3-3-3-composite	do	43	33.0	38.8	19.6	8.1	59.0	4.2	83.5	10.43

[a] The dates of tasseling and of silking are recorded as the number of days after June 30.
[b] Used in the correlation studies within inbred lines but not as the parents of crosses.

TABLE 2.—*Crossing-block row numbers, pedigree numbers, parent varieties, and the means for the different characters in all of the crossbred progeny of each inbred parent line of corn in 1926*—Continued

Color group and crossing block-row No.	Pedigree No.	Parent variety	Means for the different characters in the crossbred progeny of each inbred line								
			Crosses averaged	Date of—[a] Tasseling	Date of—[a] Silking	Shrinkage of the harvested ears	Plant height	Plants erect at harvest	Ears moldy	Shelling percentage	Yield per row
Yellow corn:			*No.*			*P.ct.*	*Feet*	*P.ct*	*P.ct.*		*Lbs.*
158	415-5-4-4-composite	McCulloch's Reid	9	34.3	38.6	19.3	8.0	71.1	5.0	83.5	10.39
159	418-2-6-1-composite	Osterland's Reid	9	30.7	37.8	14.8	7.2	87.5	9.8	82.0	8.65
160	419-2-2-4-composite	do	43	32.0	36.0	16.5	8.1	75.7	5.5	83.4	10.92
161	420-2-7-5-composite	do	9	30.6	36.2	21.2	7.7	87.6	6.0	83.5	11.09
162	433-2-3-1-composite	Clark Yellow Dent	9	35.0	39.7	17.6	8.2	43.5	3.9	81.6	9.63
163[b]	440-1-3-7-composite	do									
164	447-5-1-8-composite	do	9	27.5	32.9	12.3	7.3	86.1	4.3	81.8	10.30
165	451-1-5-1-composite	Walden Dent	9	33.4	38.6	20.2	7.8	75.4	5.2	84.7	9.75
166	460-4-1-5-composite	do	9	33.8	38.6	19.0	8.2	69.2	3.2	82.9	10.30
167	461-2-1-4-composite	do	9	38.4	43.0	20.3	9.0	58.3	2.0	84.2	10.28
168	465-3-1-4-composite	do	43	32.8	37.1	13.6	7.8	77.0	1.8	83.4	10.41
169	467-1-4-4-composite	do	9	31.5	36.9	20.7	8.0	71.5	3.5	83.6	10.92
170	477-4-2-2-composite	Argentine Flint	9	32.8	39.6	16.5	7.8	84.7	3.4	85.5	9.01
171	483-5-4-4-composite	do	43	33.2	38.8	23.1	7.8	51.1	3.0	83.5	10.40
172	487-5-1-2-composite	do	9	31.8	36.4	17.8	7.8	64.4	1.9	84.9	10.27
173	493-3-1-1-composite	do	9	35.0	42.2	22.5	7.6	55.7	1.1	81.9	9.07
174[c]	Holbert's A-1-1-2-R-1-2-3-7-1.	Funk Bros. 176 A	9	33.6	38.1	18.4	7.8	68.6	2.3	82.7	10.81
175[c]	Holbert's B-1-1-3-R-10-1-12-14.	do	8	37.0	41.6	19.6	8.3	65.4	5.2	83.8	9.89
176[c]	Holbert's G-8-8-1-B-2-2.	Griffin's Reid	9	32.8	36.8	17.2	8.4	66.9	2.3	83.3	9.88
	Mean			33.1	37.9	17.7	8.0	70.2	3.6	83.4	10.65

[a] The dates of tasseling and of silking are recorded as the number of days after June 30.
[b] Used in the correlation studies within inbred lines but not as the parents of crosses.
[c] Used as the parents of crosses, but no data on the lines themselves were available for use in the correlation studies.

The F_1 crosses were made in 1925 and 1926. Those made in 1925 were compared for yield in 1926, and those made in 1926 were compared for yield in 1927. The lines developed at Ames had been selfed for three generations prior to crossing in 1925, and for four generations prior to crossing in 1926. Lines Nos. 41 and 176, received from Doctor Holbert, had been inbred for 5 generations, No. 42 for 7 generations, and Nos. 174 and 175 for 8 generations. Line No. 112, from Doctor Lindstrom, had been inbred for 2 generations when crossed.

The varieties represented in the experiments and the number of inbred lines originating from each are shown in Table 3. In all, 140 lines from 18 varieties were used as the parents of crosses and 142 lines from 14 varieties in the correlation studies within inbred lines.

TABLE 3.—*Numbers of inbred lines from different varieties of corn used in the experiments*

Parent variety	Number of inbred lines			
	Used as the parents of crosses in the year stated			Included in the correlations
	1925	1926	Total	
Four-County White	15	9	24	24
Silver King	3	1	4	4
C. I. 133	4	2	6	7
Iodent	18	13	31	34
C. I. 204	3	1	4	5
Lancaster Surecrop	4	6	10	11
Black's Reid Yellow Dent	3	4	7	8
Proudfit's Reid Yellow Dent	3	2	5	6
Krizer Bros. Yellow Dent	3	3	6	7
McCulloch's Reid Yellow Dent	3	4	7	7
Osterland's Reid Yellow Dent	4	3	7	7
Clark Yellow Dent	4	2	6	7
Walden Dent	3	5	8	7
Argentine Flint	4	4	8	8
Western Flint	1	0	1	0
White Flint	0	1	1	0
Funk Bros. 176 A	2	2	4	0
Griffin's Reid Yellow Dent	0	1	1	0
Total	77	63	140	142

EXPERIMENTAL METHODS

Throughout the selection of the inbred lines extreme care has been exercised to prevent accidental outcrossing. All of the self-pollinations since the experiments were started have been made by the bottle method already described (*3*). Very little outcrossing has occurred. For example, in 1926 less than 0.4 per cent of outcrossed plants occurred in the selfing plots. At this time the lines had been inbred for four generations, and outcrossed plants could be distinguished readily by their greater size and vigor.

MAKING THE F_1 CROSSES

In comparing the inbred lines as parents an attempt was made to use each line in at least 10 crosses. All of the crosses were made in a special group of rows called the crossing block. Several different methods were followed. In 1925 each row in the crossing block was from the seed of an individual ear. In 1926 seed from three to five selfed ears was mixed to represent each line.

The 80 inbred lines in the 1925 crossing block (Nos. 1–80, Table 1) were divided into three groups. The first group, Nos. 1 to 20, were from varieties of white corn; the second group, Nos. 21 to 40, were from early varieties of yellow corn; and the third group, Nos. 41 to 80, were from the later varieties of yellow corn. Lines 8, 23, and 44 were weak and undesirable and therefore were discarded. This left 19 lines in each of the first two groups and 39 in the third group.

Within the first group, each of the lines 1 to 10, inclusive (except 8), was crossed with each of the lines 11 to 20, inclusive, resulting in 90 different combinations. Similarly, in the second group, lines 21 to 30, inclusive (except 23), were crossed with lines 31 to 40, inclusive. This also gave 90 different combinations. In both groups the crosses were made reciprocally, and the seed from reciprocal crosses was

mixed for use in the yield experiments. A slightly different procedure was followed in the third group. Here, 10 of the 39 lines were selected as sires, and an attempt was made to cross each sire with each of the remaining 29 lines. Of the 290 possible combinations, 281, or all but 9 combinations, were obtained. No reciprocal crosses were made in this group.

The 1926 crossing block contained 76 inbred lines (Nos. 101 to 176, Table 2). Lines 101 to 113, inclusive, were from varieties of white corn. Two of these were discarded, the 11 best-appearing lines being selected for crossing. An attempt was made to obtain all possible combinations among these 11 lines. Of the 55 possible combinations, 53 were obtained. Seed of reciprocals was mixed for use in the yield experiments. Lines 114 to 176, inclusive, were from yellow corn. For various reasons 10 of these were discarded, leaving 53 lines. Of these, 10 were selected as sires and were crossed with each of the other 43 lines. Reciprocal crosses were not made in this group. Later in the season, after the crosses had been made, one of the lines used as a sire developed undesirable characteristics and all crosses with it were discarded. All but 4 of the 387 possible combinations (9 sires with each of 43 lines) were obtained.

In making all crosses, pollen from 12 to 15 plants of the row used as the male parent was mixed together and three to six ears were pollinated in each row used as a female parent. This tended to avoid the effect of individual plant variation. In the three groups of lines where reciprocal crosses were made and the seed mixed, therefore, from 12 to 20 plants in each of the parental lines were represented in the cross. In the two groups where reciprocal crosses were not made, 12 to 15 plants of the male parent and 3 to 6 plants of the female parent were represented in the cross.

The technic employed in making the crosses was similar to that described by Coulter (*1*). A half-ounce bottle was used to hold the pollen, instead of a thistle tube. The top of the bottle was fitted with a 2-hole rubber stopper. Two pieces of glass tubing were inserted, as for an ordinary wash bottle. The pollen then was blown onto the silks. In this way it was easy to make 50 to 60 cross pollinations with one collection of pollen.

YIELD EXPERIMENTS

All data on the inbred parent lines used in the correlation studies were obtained in a special yield experiment in 1926. At this time the lines had been selfed for four generations. The seed used to represent a line of the 1925 crossing block was a mixture from several selfed progeny ears of the ear used in that crossing block. The seed used to represent a line of the 1926 crossing block was from the same mixtures as those used to plant that crossing block.

Each line was planted in three distributed 15-hill, 1-row plots. Every tenth plot was planted to the same inbred line to provide a uniform check. Because of a shortage of seed, only three kernels per hill were planted, and the plants were not thinned.

The data on the F_1 crosses used in these studies were obtained from special yield experiments conducted in 1926 and 1927. The three groups of F_1 crosses, white, early yellow, and late yellow, which were made in the 1925 crossing block were compared in the 1926 experiments, and the two groups of F_1 crosses, white and yellow,

which were made in the 1926 crossing block were compared in the 1927 experiments. In each experiment six distributed 1-row plots, each 15 hills long, were planted with each kind of corn. In order to obtain more uniform stands, four kernels per hill were planted and later the plants were thinned to three per hill. In the 1926 experiments, every tenth plot was planted to a uniform check. No check plots were planted in the 1927 experiments.

All yields are reported as pounds of air-dry shelled corn per row. The percentage of moisture in the comparison of inbred lines was determined by drying the entire yield from each plot. In the 1926 comparison of crosses the percentage of moisture was determined from a shrinkage sample of 15 random ears taken from each plot. In the 1927 experiments the entire yield from two of the six replications of each kind of corn was dried. The average moisture content of the shrinkage samples after they had become air dry was 5.57 per cent for the experiments conducted in 1926, 5.69 for the comparison of white crosses in 1927, and 7.19 per cent for the comparison of yellow crosses in 1927. The yields in pounds per row may be converted to acre yields in bushels of grain containing 15 per cent of moisture by multiplying by the following factors:

For all of the 1926 experiments	5.191
For the white crosses, 1927	5.184
For the yellow crosses, 1927	5.102

In both the 1926 and the 1927 yield experiments the six plots of each kind of corn were distributed at random over the field. In the 1926 experiments, however, the first replication was planted in the order of the pedigree numbers of one inbred parent and the second replication was planted in the order of the pedigree numbers of the other parent. The four packets of seed of each kind of corn for the remaining four replications then were put together in a churn and thoroughly mixed. They then were drawn at random from the churn and planted in that order. In 1927 six packets of seed were made up of each kind of corn, one packet for each replication. The packets for each replication, however, were mixed separately, so that there was random distribution within each replication, but the different replications were kept separate and distinct.

YIELD COMPUTATIONS

The data were recorded on punch cards which then were used with mechanical sorting and tabulating machines. In this way no more effort was required to collect the data from the various plots of each kind of corn with a random distribution than would have been required with a systematic distribution.

Yields were adjusted for variations in soil productivity and in stand. Adjustments for soil heterogeneity were made according to the regression of the individual rows on a 5-row moving average, as suggested by Richey (*9*). Adjustments for stand were made according to the regression of yield on stand. The essentially different feature of the process used was that these two adjustments were made on the basis of one multiple regression equation which took account of variation in both soil and stand. The various correlations among stand, the 5-row moving average, and the deviation of the yield of each plot from the mean yield of all plots of the same kind of

corn first were calculated. From these correlations a multiple regression equation of the form

$$\overline{D} = \beta_{DS} \frac{\sigma_D}{\sigma_S} S + \beta_{DA} \frac{\sigma_D}{\sigma_A} A$$

was determined. In this $\overline{D}$ represents the predicted and D the observed deviation in yield of any plot from the mean yield of all plots of the same kind of corn, S represents the deviation in stand of any plot from the mean stand of the experiment, A, the moving average value, and β indicates the partial regression coefficients. Actually only the mean yields of the different kinds of corn were adjusted. Then $\overline{D}$ represents the correction term to be applied to the mean S, the mean deviation in stand of all plots of the same kind of corn, and A their mean moving average value.

A general standard deviation was calculated for each experiment. The formula used was the usual one of

$$\sigma_E = \sqrt{\frac{\Sigma d^2}{N}}$$

in which d is the deviation of each plot from the mean of all plots of the same kind of corn. The standard deviation of the difference between any two mean yields was then calculated according to the formula suggested by Richey (*9*) as follows:

$$\frac{2s\ \sigma^2_E\ (1-R^2)}{(s-1)\ \ (n-1)}$$

in which s is the number of plots used in computing the moving average, n is the number of replications, and R is the multiple correlation of stand and moving average with yield.

COLLECTING DATA ON CHARACTERS STUDIED

A list of all of the characters treated as variables in the correlation studies is given in Table 4. The symbols used throughout to designate the respective variables are shown at the left of the table. Table 4 also shows the units of measurement and least measurements used in taking the data on the variables and the class intervals used in calculating the coefficients of correlations. In general, the size of the class interval was arranged so as to give 10 classes.

Data on the characters studied were taken on each replication of the yield experiments, except that the date of tasseling, date of silking, plant height, nodes per plant, and nodes below ear were determined on only two replications of the F_1 crosses. The final values used in the correlation tables were the means of the values determined for the different replications.

The date of tasseling and date of silking are based on the date on which 10 plants in the row (approximately one-fourth of the plants) tasseled or silked. The dates are recorded as the number of days after June 30. A plant was counted as tasseled as soon as anthers appeared.

TABLE 4.—*Variables, units of measurements, and least measurements used in taking the data, and the class intervals used in calculating the coefficients of correlation*

Symbol	Variable	Units of measurement and least measurements	Class intervals	
			Inbred	F_1 crosses
A	Date of tasseling	1 day	1 day	½ day.
B	Date of silking	do	do	Do.
C	Shrinkage of the harvested ears	1 per cent	2.3 per cent	½ per cent.
D	Chlorophyll	1 grade	0.3 grade	
E	Plant height	0.5 foot	0.5 foot	0.5 foot.
F	Nodes per plant	Actual number	0.5 node	0.8 node.
G	Nodes below ear	do	0.3 node	0.5 node.
H	Percentage of nodes below ear	1 per cent	2.2 per cent	2.2 per cent.
I	Plants smutted	do	5.1 per cent	5.1 per cent.
J	Plants erect at harvest	do	11 per cent	11 per cent.
K	Ears moldy	do	8.2 per cent	6 per cent.
L	Suckers per 100 plants	Actual number	7.2 suckers	7.2 suckers.
M	Plants with 2 or more ears	1 per cent	9 per cent	2.5 per cent.
N	Ears per plant	Actual number	0.09 ear	0.09 ear.
O	Ear length	0.1 cm	0.9 cm	0.1 cm.
P	Ear diameter	do	0.216 cm	0.15 cm.
Q	Ear-shape index (diameter÷length)	0.001	0.025	0.020.
R	Kernel rows per ear	Actual number	0.8 row	1 row.
S	Shelling percentage	1 per cent	2.1 per cent	1.05 per cent.
T	Coefficient of variablity of number of kernel rows.	0.1 per cent	1.6 per cent	
X	Yield	0.2 pound	0.7 pound	0.7 pound.
Y	Mean yield of crosses	0.01 pound	0.45	

Data on chlorophyll grade were taken on the inbred lines only. Five arbitrary color grades were established. These grades were numbered 1 to 5, inclusive, grade 1 being the darkest color and grade 5 the lightest. Each replication of the inbred lines was graded. The average of the grades given the three replications was taken to represent the line.

Plant height was determined by measuring several representative plants in the row. The mean of these measurements then was computed.

Nodes per plant were the means of the numbers of nodes above the surface of the ground for the first 10 plants in the row. Nodes below ear were determined in a similar manner. When there were two ears the number of nodes was determined to the upper ear. The percentage of nodes below the ear was computed from these data.

Plants smutted, plants erect at harvest, ears moldy, suckers per 100 plants, plants with two or more ears on the main stalk, and ears per plant are self-explanatory. They were determined from the total counts for all replications.

Data on shrinkage of the harvested ears, ear length, ear diameter, ear-shape index, number of kernel rows per ear, and shelling percentage were obtained from the drying samples taken from each plot at harvest. These data were taken only on the inbred lines and on the F_1 crosses compared in 1926.

The coefficient of variability for kernel rows per ear was determined for the inbred lines only.

COMPUTATION OF COEFFICIENTS OF CORRELATION

All of the coefficients of correlation of the zero order, the partial correlations, and the multiple correlations were calculated according to the methods suggested by Wallace and Snedecor (*11*). The computations were carried to two more places than those reported.

The class intervals shown in Table 4 were used in calculating all of the coefficients of correlation except where otherwise stated. Sheppard's correction was not used to correct for the fact that the data were coded.

ADJUSTING FOR HETEROGENEITY OF DATA

Inbred lines from 14 varieties have been included in the present experiments. Some of these varieties differ widely in practically all of the characters studied. In order to group the inbreds from all of these varieties into the same correlation tables, it was necessary to adjust for heterogeneity of material. The method finally adopted was to express the value for any character in an inbred line as a deviation from the mean value of that character in all lines of the variety from which the given line originated. The writer is not entirely satisfied that this is the best method that could have been used. It may be that expressing the value of a character of any line as a percentage of the mean of that character in all of the lines from the same variety would have been more desirable because it would have given more weight to deviations from small means. The method used, however, measures without distortion the average tendency of the variously paired characters toward concomitant variation around the means of the different parent-varietal groups.

The same general method was used with the F_1 crosses grown in 1926, the only ones within which correlations were computed. The parent lines of these crosses had been grouped into three more or less uniform groups (white, early yellow, and late yellow). The mean of each character for each group therefore was determined, and the characters of each F_1 cross were then expressed as deviations from the mean of the group in which that cross occurred.

COEFFICIENTS OF SIMPLE CORRELATION WITHIN INBRED LINES

For convenience in studying the interrelations among the different variables, they have been divided into seven groups of more or less related characters. Except where otherwise stated, the same grouping has been maintained in all of the correlation studies reported. These groups are described as follows:

Group 1.—Characters indicating the relative length of season required to reach maturity, comprising date of tasseling, date of silking, and shrinkage of the harvested ears.

Group 2.—Characters indicating the relative vigor and size of the plants in the different lines and crosses, comprising chlorophyll grade, plant height, nodes per plant, nodes below the ear, and percentage of nodes below the ear.

Group 3.—Characters indicating the relative susceptibility to disease of the different lines and crosses, comprising plants smutted, plants erect at harvest, and ears moldy.

Group 4.—Characters indicating the relative branching habits of the plants, comprising suckers per 100 plants, plants with two or more ears, and ears per plant.

Group 5.—Characters of the harvested ears, comprising ear length, ear diameter, ear-shape index, kernel rows per ear, and shelling percentage.

Group 6.—The coefficient of variability of number of kernel rows, which may be taken as an index of the heterozygosity of the parent inbred lines.

Group 7.—Yield. In some of the parent-progeny correlations the mean yield of all crosses for the parent lines was placed in this group.

The coefficients of simple correlation among the different characters studied in the inbred lines are shown in Table 5. Coefficients which are three or more times their probable errors are considered significant and are printed in boldface type.

Of the 210 coefficients of correlation in Table 5, 65 may be considered significant statistically, as judged by the fact that they are three or more times their probable errors. A summary of the positive and negative relations among the different variables, as indicated by the significant coefficients of correlation in Table 5, is given.

All of the coefficients in Table 5 are between plant or ear characters in the same generation. Their size, therefore, affords an approximate measure of the relative ease with which various combinations of characters could be obtained by selection. It is common knowledge among corn breeders, however, that inbred lines tend to breed true in successive generations. This tendency, which has been shown quantitatively by Hayes (*2*), gives to these coefficients much of the significance of parent-progeny correlations.

The most interesting correlations shown in Table 5 are those with yield of the inbred line. The highest positive correlation of yield with another variable was that of 0.39 with shelling percentage. The other characters which were significantly and positively correlated with yield were ear length (0.38), ear diameter (0.32), ears per plant (0.31), and plant height (0.20). The characters which were significantly and negatively correlated with yield were shrinkage of the harvested ears (−0.27), date of silking (−0.26), chlorophyll grade (−0.21), and ear-shape index (−0.17). The first two of these negative correlations indicate that late maturity was associated with low yields. Within inbred lines late maturity often is due to a general lack of vigor resulting from the presence of deleterious characters. It is possible that the low yields may have been due to reduced vigor as reflected in late maturity rather than to inherent lateness alone. The negative correlation with ear-shape index indicates that the larger yields comprised relatively long, slender ears. It should be remembered that grade 1 of chlorophyll was the darkest green and grade 5 the lightest. The negative correlation here, therefore, indicates that the dark-green plants were higher yielding.

Date of tasseling and date of silking were significantly and positively correlated with shrinkage of the harvested ears, plant height, nodes per plant, nodes below ear, and plants with two or more ears. The correlation between date of tasseling and shrinkage was 0.37, and that between date of silking and shrinkage was 0.46. This indicates that date of silking was a better index of relative maturity among these inbred lines than was date of tasseling.

The percentage of plants erect at harvest was correlated significantly and negatively with three variables. The highest correlation was that with ears moldy. It naturally would be expected that those lines in which a large number of the plants were down, with many of the ears resting on the ground, would have more moldy ears than lines with erect plants.

Ear-shape index was correlated significantly and positively with shrinkage of the harvested ears, ears moldy, ear diameter, and kernel rows per ear, and was significantly and negatively correlated with ears per plant and ear length. The correlations with ear length, ear diameter, and number of kernel rows naturally would be expected. Those with ears moldy and with shrinkage of the harvested ears indicate that the relatively short, thick ears were more inclined to be moldy and that they shrank the most.

TABLE 5.—*Coefficients of simple correlation among various characters within inbred lines of corn*

[NOTE.—Coefficients of 0.17 are 3 times their P. E. (probable error), those of 0.22 are 4 times their P. E., those of 0.26 are 5 times their P. E., those of 0.31 are 6 times their P. E. those of 0.39 are 8 times their P. E., and those of 0.45 are 10 times their P. E. Coefficients three or more times their P. E. are printed in boldface type]

Group No. and symbol	Variable	Yield	Date of—		Shrinkage of harvested ears	Chlorophyll grade	Plant height	Number of nodes		Percentage of nodes below ear	Plants smutted	Plants erect at harvest	Ears moldy	Suckers per 100 plants	Plants with two or more ears	Ears per plant	Ear length	Ear diameter	Ear-shape index	Kernel rows per ear	Shelling percentage
			Tasseling	Silking				Per plant	Below ear												
		X	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
A	Date of tasseling	−0.15																			
1 B	Date of silking	−.26	**0.81**																		
C	Shrinkage of the harvested ears	−.27	.37	**0.46**																	
D	Chlorophyll grade	−.21	−.03	.06	0.02																
E	Plant height	.20	.37	.36	.12	−0.11															
2 F	Nodes per plant	.06	.44	.34	.20	.00	**0.54**														
G	Nodes below ear	.16	.45	.38	.17	−.15	.43	**0.65**													
H	Percentage of nodes below ear	.12	.13	.15	.01	−.17	.01	−.08	**0.67**												
I	Plants smutted	−.07	.06	.00	.07	−.09	−.01	−.08	−.04	0.02											
3 J	Plants erect at harvest	.07	−.18	−.11	−.15	−.12	.11	−.19	−.16	−.04	0.12										
K	Ears moldy	−.16	−.06	−.04	.04	−.07	−.06	.12	.05	−.08	.00	**−0.20**									
L	Suckers per 100 plants	.10	.12	.10	.08	.02	.05	.05	−.10	−.16	.19	.05	−0.06								
4 M	Plants with two or more ears	.11	.32	.19	.02	−.18	.26	.35	.47	.27	−.09	−.05	.11	0.08							
N	Ears per plant	.31	.18	.05	−.10	−.18	.27	.26	.30	.16	−.14	.09	.01	.34	0.79						
O	Ear length	.38	−.13	−.21	−.40	−.13	−.03	−.08	−.01	.04	−.11	.15	−.15	−.03	−.19	0.03					
P	Ear diameter	.32	−.20	−.23	−.02	−.08	−.07	−.13	−.05	.03	.04	.12	.06	−.22	−.36	−.29	**0.26**				
5 Q	Ear-shape index	−.17	−.03	.02	.37	.06	−.03	.00	−.02	−.02	.15	−.08	.26	−.11	−.06	−.21	−.76	**0.31**			
R	Kernel rows per ear	.04	−.08	.01	.10	.01	−.02	−.13	−.05	.05	−.02	.08	−.02	−.11	−.23	−.25	−.10	.50	0.37		
S	Shelling percentage	.39	−.15	−.26	−.14	.01	−.19	−.04	−.05	−.03	−.02	−.01	.07	.00	.00	.07	.14	.30	.03	0.13	
6 T	Coefficient of variability of number of kernel rows	.12	.04	−.05	.07	−.05	−.11	.10	.14	.05	−.02	−.02	.11	−.08	.03	.00	.21	.07	−.13	−.12	0.04

SUMMARY SHOWING THE SIGNIFICANT POSITIVE AND NEGATIVE RELATIONS AMONG THE DIFFERENT VARIABLES

Symbol	Variable	Characters with which the variable indicated was significantly correlated in the direction stated		Symbol	Variable	Characters with which the variable indicated was significantly correlated in the direction stated		Symbol	Variable	Characters with which the variable indicated was significantly correlated in the direction stated	
		Positive	Negative			Positive	Negative			Positive	Negative
A	Date of tasseling	BCEFGMN	JP.	H	Percentage of nodes below ear.	GM	D.	O	Ear length	PTX	BCMQ.
B	Date of silking	ACEFGM	OPSX.	I	Plants smutted	L		P	Ear diameter	OQSRX	ABLMN.
C	Shrinkage of the harvested ears.	ABFGQ	OX.	J	Plants erect at harvest		AFK.	Q	Ear-shape index	CKPR	NOX.
D	Chlorophyll grade		HMNX.	K	Ears moldy	Q	J.	R	Kernel rows per ear	PQ	MN.
E	Plant height	ABFGMNX	S.	L	Suckers per 100 plants	IN	P.	S	Shelling percentage	PX	BE.
F	Nodes per plant	ABCEGMN	J.	M	Plants with two or more ears.	ABEFGHN	DOPR.	T	Coefficient of variability of number of kernel rows.	O	
G	Nodes below ear	ABCEFHMN		N	Ears per plant	AEFGLMX	DPQR.	X	Yield	ENOPS	BCDQ.

COEFFICIENTS OF PARTIAL AND OF MULTIPLE CORRELATION WITHIN INBRED LINES

Coefficients of partial correlation between yield and other characters of the inbred lines were determined for most of the variables in Groups 1, 2, 3, and 5. The percentage of nodes below the ear was omitted from Group 2, and ear-shape index was omitted from Group 5, as they are both ratios, and partial correlations involving them are likely to be misleading. All of the characters in Group 4 and kernel rows per ear in Group 5 also were omitted.

Partial correlations were computed between each character of each group and the yield of the inbred line, thus eliminating the effect of the variation of the remaining characters of the group. The coefficients of multiple correlation for yield and all of the characters in each group also were computed. These correlations are recorded in Table 6.

TABLE 6.—*Coefficients of partial and of multiple correlation between yield and four groups of the other characters of the inbred lines*

Group No.	Designation of coefficient	Coefficients of correlation	Group No.	Designation of coefficient	Coefficients of correlation
1	$r_{AX \cdot CB}$	0.11±0.06	3	$r_{IX \cdot JK}$	−0.08±0.06
	$r_{BX \cdot AC}$	−.18± .06		$r_{JX \cdot IK}$	.05± .06
	$r_{CX \cdot AB}$	−.18± .06		$r_{KX \cdot IJ}$	−.15± .06
	$R_{X \cdot ABC}$	.33± .05		$R_{X \cdot IJK}$	.18± .06
2	$r_{DX \cdot EFG}$	−.17± .06	5	$r_{OX \cdot PS}$	.31± .05
	$r_{EX \cdot DFG}$	.17± .06		$r_{PX \cdot OS}$	.17± .06
	$r_{FX \cdot DEG}$	−.09± .06		$r_{SX \cdot OP}$	.31± .05
	$r_{GX \cdot DEF}$	.10± .06		$R_{X \cdot OPS}$	.52± .04
	$R_{X \cdot DEFG}$	.30± .05		$R_{X \cdot ABCDEFGKMOPS}$	.69± .03

The ear characters (Group 5) were most highly correlated with yield. This was to be expected, as these characters represented the physical description of the ears constituting yield itself. The correlation between yield and the group of characters indicating relative disease susceptibility (Group 3) was the lowest. There was but little difference between the multiple correlations for yield with characters of the remaining two groups. The multiple correlation between yield and 12 of the other characters, 0.69 ± 0.03, also is recorded in Table 6.

Of the characters in Group 1, date of tasseling (A) was positively though not significantly correlated with yield, and date of silking (B) and shrinkage of the harvested ears (C) each were negatively and significantly correlated with yield, when the remaining characters of the group were held constant.[4]

[4] The term "held constant" is used throughout in the sense that the effect of the variation has been eliminated.

It is interesting to speculate as to why date of tasseling gave a positive partial correlation with yield, and date of silking a negative partial correlation. In order to eliminate any confusing effect of the shrinkage of the harvested ears, partial correlations were computed between date of tasseling and yield for constant date of silking and between date of silking and yield for constant date of tasseling. The first of these correlations ($r_{AX.B}$) was 0.11 ± 0.06 and the second ($r_{BX.A}$) was -0.24 ± 0.05. Holding either one of these dates constant and permitting the other to vary was equivalent to varying the number of days from tasseling to silking. With the date of tasseling constant, the later silking plants were those with a longer period from tasseling to silking, inasmuch as most of the strains were protandrous. According to the negative partial correlation between yield and date of silking, these plants yielded somewhat less. Similarly, with the date of silking constant, the earlier tasseling plants are those with a longer period from tasseling to silking, which likewise, according to the positive partial correlation between date of tasseling and yield, were less productive. Both of the partial correlations therefore indicate that a decrease in the number of days from tasseling to silking was accompanied by a higher yield. Plants which are decidedly protandrous are difficult to self. The tendency, therefore, in selecting in selfed lines of corn is to obtain lines tasseling and silking more or less simultaneously. These correlations indicate that such a tendency is at least not objectionable.

The partial correlations between yield and two of the characters in Group 2 were positive and between yield and two other characters in this group were negative. One of the positive and one of the negative correlations verged on significance. Plant height (E) was positively associated with yield when chlorophyll grade (D), nodes per plant (F), and nodes below ear (G) were constant. The partial correlation of chlorophyll grade with yield was negative when the other members of Group 2 were held constant. As noted, this indicates that the darker chlorophyll grades were associated with larger yields.

Only one of the members of Group 3 was appreciably correlated with yield when the other members of the group remained constant, and it can not be considered significant. This was ears moldy (K), for which a negative partial correlation of -0.15 ± 0.06 was obtained.

Significant positive partial correlations were obtained between yield and two of the characters of Group 5. The partial correlation between ear length and yield for constant diameter and shelling percentage was 0.31 ± 0.05, whereas that between ear diameter and yield for constant length and shelling percentage was 0.17 ± 0.06. The high partial correlation between shelling percentage and yield (0.31 ± 0.05) may have been due in part to the poorly filled ears that occurred in many inbred lines.

These correlations indicate that, for the season in which they were grown, those inbred lines tended to be higher yielding which matured rather early, belonged to the darker chlorophyll grades, were relatively tall, produced relatively many ears (few barren plants), and produced large ears which were longer, rather than greater in diameter, than the average. The ears of the more productive lines also had a high percentage of grain.

TABLE 7.—*Coefficients of simple correlation among various characters within F_1 crosses between inbred lines of corn*

[NOTE.—Coefficients of 0.09 are 3 times their P. E. (probable error), those of 0.12 are 4 times their P. E., those of 0.15 are 5 times their P. E., those of 0.18 are 6 times their P. E. those of 0.24 are 8 times their P. E., and those of 0.29 are 10 times their P. E. Coefficients three or more times their P. E. are printed in boldface type]

Group No. and symbol	Variable	Yield	Date of—		Shrinkage of the harvested ears	Plant height	Number of nodes		Percentage of nodes below ear	Plants smutted	Plants erect at harvest	Ears moldy	Suckers per 100 plants	Plants with two or more ears	Ears per plant	Ear length	Ear diameter	Ear-shape index	Kernel rows per ear
			Tasseling	Silking			Per plant	Below ear											
		X	A	B	C	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	A Date of tasseling	**0.18**																	
	B Date of silking	.16	**0.75**																
	C Shrinkage of the harvested ears	−.06	.19	**0.27**															
2	E Plant height	.33	.15	.26	**0.13**														
	F Nodes per plant	.35	.40	.28	.17	**0.38**													
	G Nodes below ear	.31	.39	.31	.22	.30	**0.78**												
	H Percentage of nodes below ear	.03	.10	.12	.11	−.03	.03	**0.56**											
3	I Plants smutted	−.23	.07	.13	.14	.08	.04	.05	**0.03**										
	J Plants erect at harvest	−.05	−.12	−.14	−.11	−.11	−.19	−.19	.09	**0.00**									
	K Ears moldy	.18	.07	.07	−.02	−.05	.03	.08	.08	.28	**−0.33**								
4	L Suckers per 100 plants	.00	.03	−.01	.08	−.02	.00	.02	.03	.12	.06	**0.09**							
	M Plants with two or more ears	−.01	.18	.07	.17	.10	.26	.24	.05	.07	−.09	−.02	**0.20**						
	N Ears per plant	.09	.06	.00	.14	.01	.06	.06	.02	.05	.04	−.10	.65	**0.53**					
	O Ear length	.42	.23	.21	.10	.28	.21	.15	−.05	−.12	−.17	−.09	−.07	.13	**0.04**				
	P Ear diameter	.25	.10	.12	−.03	.02	.01	.06	.05	−.04	.16	−.01	−.11	−.32	−.22	**−0.18**			
5	Q Ear-shape index	−.27	−.21	−.17	−.10	−.21	−.19	−.15	.03	.07	.20	.07	.04	.27	.18	−.66	**0.56**		
	R Kernel rows per ear	−.02	.10	.15	−.03	−.14	−.10	−.09	.00	.02	.16	.02	−.05	−.21	−.22	−.43	.58	**0.56**	
	S Shelling percentage	.31	−.11	−.11	−.15	−.07	−.01	.05	.09	.01	.01	.12	.11	−.12	−.02	−.14	.31	.23	**0.28**

SUMMARY SHOWING THE SIGNIFICANT POSITIVE AND NEGATIVE RELATIONS AMONG THE DIFFERENT VARIABLES

Symbol	Variable	Characters with which the variable indicated was significantly correlated in the direction stated		Symbol	Variable	Characters with which the variable indicated was significantly correlated in the direction stated	
		Positive	Negative			Positive	Negative
A	Date of tasseling	BCEFGHMOPRX	JQS.	K	Ears moldy	ILS	JNOX.
B	Date of silking	ACEFGHIOPRX	JQS.	L	Suckers per 100 plants	IKMNS	P.
C	Shrinkage of the harvested ears.	ABEFGHIMNO	JQS.	M	Plants with two or more ears.	ACEFGJLNO	PQRS.
				N	Ears per plant	CLMX	KPQR.
E	Plant height	ABCFGMOX	JQR.	O	Ear length	ABCEFGMX	IJKPQRS.
F	Nodes per plant	ABCEGMOX	JQR.	P	Ear diameter	ABJQRSX	LMNO.
G	Nodes below ear	ABCEFHMOX	JQR.	Q	Ear-shape index	JPRS	ABCEFGMNOX.
H	Percentage of nodes below ear.	ABCGS		R	Kernel rows per ear	ABJPQS	EFGMNO.
I	Plants smutted	BCKL	OX.	S	Shelling percentage	IIKLPQRX	ABCMO.
J	Plants erect at harvest	MPQR	ABCEFGKO.	X	Yield	ABEFGNOPS	IKQ.

COEFFICIENTS OF SIMPLE CORRELATION WITHIN F_1 CROSSES

The coefficients of correlation among the characters within the F_1 crosses are recorded in Table 7. Coefficients three or more times their probable errors are printed in boldface type. The correlations in this table were computed from the data on the F_1 crosses grown in 1926 and, like those within inbred lines, are among characters within the same generation. In all, 461 F_1 crosses from the three 1926 yield groups are represented in these correlations.

A larger percentage of the coefficients of correlation in Table 7 are significant than of those within inbred lines. This is due principally to the larger number of observations, which resulted in smaller probable errors, rather than to material differences in the actual size of the coefficients. Of the 171 correlations recorded, 104 are statistically significant in that they are at least three times their probable errors. A summary of the data in Table 7 is given, showing which characters were correlated significantly either positively or negatively and bringing out more clearly the interrelations among the different variables.

The coefficients of correlation of primary interest are those between yield and the other characters. In general, yield was correlated positively with the characters indicating length of season required to reach maturity, plant vigor, and ear size. It was correlated negatively with the characters indicating the relative susceptibility to disease and with ear-shape index. The correlation between yield and shrinkage of the harvested ears was negative though not significant. This unimportant correlation probably was due to the fact that the season of 1926 was ideal for the ripening of the later kinds of corn, so that practically all of the crosses matured fully.

The highest correlation between yield and the other characters in the F_1 crosses was the correlation of 0.42 with ear length. The correlation of yield with ear diameter was 0.25 and that with ear-shape index was -0.27. This indicates that although both length and diameter, which go to make up size of ear, were correlated positively with yield, length of ear was a more important factor in determining larger yields than diameter of ear.

Other interesting relations are brought out in Table 7. In general, all of the characters indicating maturity or plant vigor (Groups 1 and 2) were correlated positively among themselves. Most of these characters were correlated negatively with percentage of plants erect at harvest and with ear-shape index. Evidently, the tall, vigorous plants were more likely to go down before harvest and to have long, slender ears.

Additional evidence that the down plants were those having long, slender ears is to be had from (1) the significant positive correlations of plants erect at harvest with ear-shape index and ear diameter and (2) the significant negative correlation of plants erect at harvest with ear length. The correlation already mentioned between ear characters and yield indicated that crosses with short, thick ears were less productive than those with long, slender ears. This might account for their being more erect at harvest, for they were supporting a smaller weight of ear.

In order to determine whether there were any striking differences in the coefficients of correlation in the different yield groups, the correlations between the different characters and yield were com-

puted for each group separately. The coefficients of correlation from each of the three experiments and, for comparison, the correlations for the three groups combined, are recorded in Table 8.

TABLE 8.—*Coefficients of correlation between yield and the various other characters within the different yield groups of F_1 crosses grown in 1926*

Character correlated with yield	Coefficient of correlation for the yield group indicated			
	90 white crosses	90 early yellow crosses	281 later yellow crosses	All 461 crosses of the three groups combined
Date of tasseling	0.16±0.07	0.52±0.05	0.08±0.04	0.18±0.04
Date of silking	.11± .07	.37± .06	.10± .04	.16± .04
Shrinkage of the harvested ears	−.17± .07	.10± .07	−.08± .04	−.06± .03
Plant height	.27± .07	.09± .07	.40± .03	.33± .04
Nodes per plant	.16± .07	.26± .07	.42± .03	.25± .04
Nodes below ear	.15± .07	.24± .07	.37± .03	.31± .03
Percentage of nodes below ear	.04± .07	−.06± .07	.05± .04	.03± .03
Plants smutted	−.09± .07	−.26± .07	−.23± .04	−.22± .03
Plants erect at harvest	−.13± .07	.22± .07	−.11± .04	−.05± .03
Ears moldy	−.28± .07	−.55± .05	.01± .04	−.18± .03
Suckers per 100 plants	−.26± .07	.14± .07	−.02± .04	.00± .03
Plants with two or more ears	.01± .07	−.01± .07	−.02± .04	−.01± .03
Ears per plant	.20± .07	.25± .07	.01± .04	.09± .03
Ear length	.42± .06	.61± .05	.37± .03	.42± .03
Ear diameter	.41± .06	.44± .06	.13± .04	.25± .03
Ear-shape index	−.20± .07	−.27± .07	−.28± .04	−.27± .03
Kernel rows per ear	.07± .07	.29± .07	−.15± .04	−.02± .03
Shelling percentage	.50± .06	.49± .05	.20± .04	.31± .03

For the most part the coefficients of correlation between the various characters and yield (Table 8) are fairly consistent in the different yield groups. They vary somewhat in size in the different experiments, but in only a few cases are they significant and positive in one group and significant and negative in another. The correlation between yield and the percentage of plants erect at harvest is positive in the early yellow crosses and negative in the late yellow crosses. It is negative also in the white crosses, but is not significant. No explanation can be offered for this fact.

Practically the same situation is true for the correlation between kernel rows per ear and yield. It is positive in the early yellow crosses and negative in the later crosses; that is, high yield was associated with the higher rowed sorts of the early corn and the fewer rowed sorts of the later corn. A possible explanation for this may be found in the fact that the mean numbers of kernel rows were 13.4 for the early yellow crosses and 16.4 for the late yellow crosses. Both correlations therefore point to a type intermediate between these groups as better suited to the conditions at Ames in 1926. This explanation is supported by several other correlations, which indicate that late maturity and large ear size were of more importance in determining high yield in the two groups of early crosses, where the ear size was relatively small, than in the group of later crosses with their correspondingly larger ears. Date of tasseling, date of silking, ears per plant, ear length, ear diameter, and shelling percentage were correlated more highly with yield in the two groups of early crosses than in the group of late crosses.

Ears moldy also were correlated with yield more highly in the two groups of early crosses than in the group of late crosses.

COEFFICIENTS OF PARTIAL AND OF MULTIPLE CORRELATION WITHIN F_1 CROSSES

Coefficients of partial and of multiple correlation were computed from the data on the F_1 crosses for the same four groups of variables that were used within the inbred lines (p. 694). Chlorophyll grade, however, was omitted, as no data on this were taken in the F_1 crosses. These correlations for the F_1 crosses are recorded in Table 9.

TABLE 9.—*Coefficients of partial and of multiple correlation between yield and four groups of the other characters of the F_1 crosses*

Group No.	Designation of coefficient	Coefficients of correlation	Group No.	Designation of coefficient	Coefficients of correlation
1	$r_{AX.BC}$	0.10±0.03	3	$r_{IX.JK}$	−0.17±0.03
	$r_{BX.AC}$	.05± .03		$r_{JX.IK}$	−.09± .03
	$r_{CX.AB}$	−.11± .03		$r_{KX.IJ}$	−.14± .03
	$R_{X.ABC}$	.21± .03		$R_{X.IJK}$	.26± .03
2	$r_{EX.FG}$	.23± .03	5	$r_{OX.PS}$	.53± .02
	$r_{FX.EG}$	.12± .03		$r_{PX.OS}$	.29± .03
	$r_{GX.EF}$	.00± .03		$r_{SX.OP}$	.33± .03
	$R_{X.EFG}$	.41± .03		$R_{X.OPS}$	.61± .02
				$R_{X.ABEFGIKOPS}$	.71± .02

As was true for the inbred lines, the multiple correlation computed between the group of ear characters (Group 5) and yield was the highest of the multiple correlations. The multiple correlation between yield and the group of characters indicating plant vigor and size (Group 2) also was high. The remaining two groups of characters were significantly correlated with yield, though the correlations were much lower. The coefficient of multiple correlation between 10 of the characters studied and yield (Table 9) was 0.71 ± 0.02.

The partial correlations in Group 1 were low, although two of them were significant. The partial correlation of yield with date of tasseling (A) was positive and significant but low, and that with date of silking (B) was not significant. In the inbred lines the partial correlation between yield and date of silking was negative and significant. The partial correlation between shrinkage of the harvested ears and yield, for constant dates of tasseling and of silking ($r_{CX.AB}$), was significant although somewhat low.

In Group 2, which was composed of characters indicating plant size and vigor, the partial correlation of yield with each variable was positive. That between plant height and yield ($r_{EX.FG}$) was the highest. The partial correlation between nodes below ear and yield ($r_{GX.EF}$) was too small to be considered significant.

The partial correlations between yield and the characters indicating relative susceptibility to disease (Group 3) were negative. Two of them were significant, and one, between plants erect at harvest (J) and yield, probably was not significant.

All three of the partial correlations between yield and the ear characters in Group 5 were positive and significant statistically. Moreover, they were all higher than the partial correlations between yield and any of the other characters studied in the F_1 crosses.

These correlations indicate that for the season of 1926 those crosses were on an average most productive which tasseled and silked rather late, were comparatively tall, had a relatively large number of nodes per plant, were comparatively free from smutted plants and moldy ears, produced relatively many ears (few barren plants), and produced large ears which were longer, rather than greater in diameter, than the average. The ears of the more productive crosses also had a high percentage of grain. This is in agreement with the results obtained within inbred lines, except that early maturity was associated with productivity within the inbred lines.

CORRELATIONS BETWEEN CHARACTERS OF INBRED PARENTS AND THOSE OF THEIR F_1 CROSSES

The coefficients of correlation between inbred parents and F_1 crosses could be computed for three different relations, (1) that between the characters of the F_1 cross and those of each parent separately, (2) that between the characters of the F_1 cross and the mean value of these characters in the two parents, and (3) that between the characters of the inbred parent and the mean value of these characters in all of their crossbred progeny.

Under the first method of computing the coefficients of correlation the F_1 crosses would be paired first with one parent and then with the other. Each cross, therefore, would appear twice in a correlation table. Under the second method each F_1 cross would be paired with the mean value for its two parents and appear in a correlation table only once. It appeared that there should be a definite relation between the coefficients calculated by the first two methods. Investigation showed that, if there is no correlation between the two inbred parents of the F_1 crosses, then $r_2 = r_1\sqrt{2}$, where r_1 is the correlation with each parent and r_2 is the correlation with the mean of the two parents.

In the present material each inbred line was crossed with enough of the other lines within its group to eliminate practically any possibility of correlation between the parents. The coefficients of correlation between the characters of the F_1 crosses and those of each parent separately could be calculated easier than could the correlations with the mean value of these characters in the two parents. Accordingly, the former correlations were calculated first and the latter were computed by multiplying by $\sqrt{2}$.

COEFFICIENTS OF CORRELATION FOR INDIVIDUAL CROSSES WITH THEIR PARENTS

The coefficients of correlation between the different characters in the F_1 crosses and the same characters in the parent lines are shown in Table 10, the correlations with each parent separately and those with the parental means being in parallel columns.

The correlations were positive and significant in every case. The highest correlation was for percentage of erect plants, although high correlations also were obtained for kernel rows per ear, nodes per plant, nodes below ear, and percentage of nodes below ear. The lowest correlation obtained was for yield. The squared coefficients measure the portion of the variance for the different characters in the crosses that is associated with variation in the parent lines. They therefore indicate those characters for which selection in the parent lines will be more and less effective in determining the type of the crosses.

TABLE 10.—*Coefficients of correlation between characters in F_1 crosses and the same characters in the parental inbred lines*

[1926 comparison of crosses]

Symbol	Character	Coefficients of correlation		Symbol	Character	Coefficients of correlation	
		With each parent separately	With the parental means			With each parent separately	With the parental means
A	Date of tasseling	0.31±0.02	0.43±0.03	K	Ears moldy	0.22±0.02	0.31±0.03
B	Date of silking	.24± .02	.34± .03	L	Suckers per 100 plants.	.39± .02	.56± .02
C	Shrinkage of the harvested ears.	.25± .02	.35± .03	M	Plants with two or more ears.	.18± .02	.25± .03
E	Plant height	.32± .02	.45± .03	N	Ears per plant	.26± .02	.36± .03
F	Nodes per plant	.42± .02	.60± .02	O	Ear length	.30± .02	.43± .03
G	Nodes below ear	.42± .02	.60± .02	P	Ear diameter	.35± .02	.49± .03
H	Percentage of nodes below ear.	.41± .02	.58± .02	Q	Ear-shape index	.34± .02	.48± .03
I	Plants smutted	.17± .02	.24± .03	R	Kernel rows per ear	.47± .02	.67± .02
J	Plants erect at harvest.	.51± .02	.72± .02	S	Shelling percentage	.39± .02	.55± .02
				X	Yield	14± .02	.20± .03

TABLE 11.—*Coefficients of correlation between yield in F_1 crosses and various characters in the parental inbred lines*

[1926 comparison of crosses]

Symbol	Characters in the inbred parent with which yields of the crosses were correlated	Coefficients of correlation		Symbol	Characters in the inbred parent with which yields of the crosses were correlated	Coefficients of correlation	
		With each parent separately	With the parental means			With each parent separately	With the parental means
A	Date of tasseling	0.12±0.02	0.17±0.03	K	Ears moldy	−0.07±0.02	−0.10±0.03
B	Date of silking	.10± .02	.13± .03	L	Suckers per 100 plants.	.03± .02	.04± .03
C	Shrinkage of the harvested ears.	.05± .02	.07± .03	M	Plants with two or more ears.	.07± .02	.10± .03
E	Plant height	.13± .02	.19± .03	N	Ears per plant	.08± .02	.12± .03
F	Nodes per plant	.17± .02	.24± .03	O	Ear length	.11± .02	.16± .03
G	Nodes below ear	.14± .02	.20± .03	P	Ear diameter	.09± .02	.13± .03
H	Percentage of nodes below ear.	−.05± .02	−.08± .03	Q	Ear-shape index	−.10± .02	−.14± .03
I	Plants smutted	−.06± .02	−.09± .03	R	Kernel rows per ear	.00± .02	−.01± .03
J	Plants erect at harvest.	−.04± .02	−.06± .03	S	Shelling percentage	.07± .02	.10± .03
				X	Yield	.14± .02	.20± .03

Table 11 shows the coefficients of correlation between yields in the F_1 crosses and various characters in the inbred parents.

The correlations in Table 11 are much lower than those in Table 10, as is to be expected. Those characters in the inbred parents which were correlated most highly with yield in the F_1 crosses, in the order of their size, were nodes per plant, yield, nodes below ear, plant height, date of tasseling, and length of ear. These characters are approximate measures of vigor and size in the inbred plants. As the correlations were positive, the larger, more vigorous inbreds produced the higher yielding crosses.

COEFFICIENTS OF CORRELATION FOR INDIVIDUAL PARENTS WITH MEANS OF THEIR CROSSES

Coefficients of correlation between the characters of each inbred parent and the mean yield of all of its crossbred progeny are shown in Table 12. Correlations between the characters in the inbred parents and the mean values of the same character in the crossbred

progeny are shown in Table 13. In computing the coefficients in Table 12, the mean yield of all crosses of each inbred line first was determined. These means then were adjusted for heterogeneity by the method already described (p. 690). The coefficients in Table 13 are reported separately for the five different yield groups. No adjustments were made for heterogeneity within a group.

The coefficients of correlation between characters in the parental inbred lines and the mean yield of the crossbred progeny (Table 12) are shown for the crosses compared in 1926 after the parents had been selfed for three generations, for those compared in 1927 after the parents had been selfed for four generations, and for both groups combined. The correlations for the crosses made after four generations of selfing are no more significant than those for the crosses made after three generations of selfing, although several of the coefficients differed markedly in the two seasons.

TABLE 12.—*Coefficients of correlation between the various characters in the inbred parents and the mean yield of their crossbred progeny*

Character in parent correlated with mean yield of crossbred progeny	Coefficients of correlation for the groups indicated		
	Crosses compared in 1926	Crosses compared in 1927	Both groups combined
Date of tasseling	0.23±0.08	−0.04±0.09	0.15±0.06
Date of silking	.15± .08	−.08± .09	.07± .06
Shrinkage of the harvested ears	.24± .08	.05± .09	.16± .06
Chlorophyll grade	−.07± .08	−.11± .09	−.08± .06
Plant height	.16± .08	.32± .08	.21± .06
Nodes per plant	.29± .07	.28± .08	.28± .05
Nodes below ear	.24± .08	.22± .08	.22± .06
Percentage of nodes below ear	−.04± .08	.03± .09	−.01± .06
Plants smutted	−.14± .08	−.03± .09	−.11± .06
Plants erect at harvest	−.04± .08	.11± .09	.01± .06
Ears moldy	−.13± .08	.05± .09	−.08± .06
Suckers per 100 plants	.02± .08	−.13± .09	−.02± .06
Plants with two or more ears	.20± .08	.12± .09	.17± .06
Ears per plant	.20± .08	.08± .09	.16± .06
Ear length	.16± .08	−.23± .08	.02± .06
Ear diameter	.23± .08	−.13± .09	.10± .06
Ear-shape index	−.09± .08	.07± .09	−.04± .06
Kernel rows per ear	.13± .08	−.04± .09	.07± .06
Shelling percentage	.19± .08	−.11± .09	.08± .06
Coefficient of variability of number of kernel rows	.16± .08	.00± .09	.10± .06
Yield	.32± .07	.12± .09	.23± .06

In 1926 there was a late fall. This was advantageous to the crosses requiring a longer season. In 1927, however, there was an early frost, which was disadvantageous to the later maturing crosses. All of the discrepancies between coefficients for the two seasons occurred in those characters which indicate large-sized ears and late maturity, such as date of tasseling, date of silking, shrinkage of the harvested ears, ear length, ear diameter, kernel rows per ear, and shelling percentage. Most of these characters were positively correlated with mean yield of crosses in 1926 but correlated either negatively or not significantly in 1927.

A few of the characters, such as plant height, nodes per plant, nodes below ear, plants with two or more ears, and yield of the inbred parent, were significantly correlated with mean yield of crosses in both groups, separately and combined. Yield of the inbred lines showed the highest positive correlation with mean yield

of crosses in 1926, a positive correlation in 1927, and the second highest positive correlation of both years combined. The highest positive correlation for both groups combined was that for nodes per plant with yield.

The coefficients of correlation between characters in the parental inbred lines and the mean value of the same character in their crossbred progeny (Table 13) are the highest correlations that were obtained in this study. In fact, many of them are high enough to be very valuable for predictive purposes. This, of course, is augmented by the fact that the means of the crosses were used, thereby smoothing out much of the random variation. The fact that the data were not adjusted for heterogeneity within the different yield groups may account for part of the size of these correlations. Varietal differences, however, can not account for the high correlations in the white crosses grown in 1926. In this group, 16 inbred lines were represented in the correlation studies. Three of these lines were from Silver King corn and the remaining 13 were from Four-County White. These two varieties are very closely related, Four-County White being practically a selected strain of Silver King. As the correlations for this group are higher, in general, than those for the other groups, heterogeneity seems to have been a factor of little importance.

TABLE 13.—*Coefficients of correlation between characters in the inbred parents and the means of the same characters for all of their crossbred progeny, as computed for each of the five different yield groups*

Character	Coefficients of correlation in the yield group indicated				
	White crosses, 1926	Early yellow crosses, 1926	Later yellow crosses, 1926	White crosses, 1927	Yellow crosses, 1927
Date of tasseling	0.86±0.04	0.71±0.08	0.65±0.06	0.28±0.19	0.61±0.06
Date of silking	.80± .06	.52± .11	.59± .07	.45± .16	.56± .06
Shrinkage of the harvested ears	.78± .06	.71± .08	.62± .07	.36± .18	.50± .07
Plant height	.52± .12	.63± .09	.53± .08	.59± .13	.60± .06
Nodes per plant	.89± .03	.86± .04	.64± .07		
Nodes below ear	.81± .06	.75± .07	.72± .05		
Percentage of nodes below ear	.58± .11	.89± .03	.75± .05		
Plants smutted	.80± .06	.24± .15	.69± .06		
Plants erect at harvest	.77± .07	.79± .06	.88± .03	.59± .13	.41± .08
Ears moldy	.46± .13	.66± .09	.25± .11	.65± .12	.24± .09
Suckers per 100 plants	.69± .09	.88± .04	.78± .04		
Plants with two or more ears	.77± .07	.32± .14	.59± .07		
Ears per plant	.40± .14	.59± .10	.58± .07		
Ear length	.37± .14	.67± .09	.80± .04		
Ear diameter	.98± .01	.78± .06	.71± .06		
Ear-shape index	.47± .13	.19± .15	.85± .03		
Kernel rows per ear	.85± .05	.92± .02	.88± .03		
Shelling percentage	.82± .05	.50± .12	.69± .06	.82± .07	.14± .09
Yield	.67± .09	.64± .09	.25± .11	.41± .17	.45± .07

Most of the coefficients in Table 13 are significant. They are all positive and of sufficient size to indicate that the characters of the inbred lines were very definitely expressed in their crossbred progeny. The high correlations in Table 13 emphasize the advantages to be gained by using the mean of several crosses as a criterion of the value of an inbred line.

COEFFICIENTS OF PARTIAL AND OF MULTIPLE CORRELATION BETWEEN CHARACTERS OF INBRED PARENTS AND MEAN YIELDS OF THEIR CROSSBRED PROGENY

Coefficients of partial and of multiple correlation, similar to those computed within the inbred lines and within the crosses, were calculated for four groups of characters of the inbred parents with the mean yields of their crossbred progeny. The groups were the same as in the correlations within inbred lines, except that yield of the inbred parent was substituted for chlorophyll grade in Group 2 (p. 690). The partial and multiple correlations computed are recorded in Table 14.

TABLE 14.—*Coefficients of partial and of multiple correlation for four groups of characters of the inbred parents and the mean yields of their crossbred progeny*

Group No.	Designation of coefficient *	Coefficient of correlation	Group No.	Designation of coefficient *	Coefficient of correlation
1	$r_{AY'.BC}$	0.20±0.06	3	$r_{IY'.JK}$	−0.14±0.06
	$r_{BY'.AC}$	−.13± .06		$r_{JY'.IK}$	−.05± .06
	$r_{CY'.AB}$	.20± .06		$r_{KY'.IJ}$	−.14± .06
	$R_{Y'.ABC}$	.31± .05		$R_{Y'.IJK}$	.20± .06
2	$r_{EY'.FGX}$	−.07± .06	5	$r_{OY'.PS}$	.10± .06
	$r_{FY'.EGX}$	.22± .06		$r_{PY'.OS}$	.16± .06
	$r_{GY'.EFX}$	.03± .06		$r_{SY'.OP}$	.12± .06
	$r_{XY'.EFG}$	.31± .05			
	$R_{Y'.EFGX}$	.42± .05		$R_{Y'.OPS}$	.28± .06

* Y' symbolizes the mean yields of the crossbred progeny.

The highest of the multiple correlations (0.42) was for mean yield of the crossbred progeny with the members of Group 2, the characters of the inbred parent indicating plant vigor and size. The second highest multiple correlation was between yield and the characters in Group 1. The multiple correlation between yield and the characters in Group 5, which was the highest both within the inbred lines and within the F_1 crosses, was not so important here.

Few of the coefficients of partial correlation between mean yield of crosses and the characters in the different groups with the remaining characters in the group held constant can be considered significant. Two of the coefficients in Group 1, $r_{AY.BC}$ and $r_{CY.AB}$, were positive and significant and one, $r_{BY.AC}$, was negative and not significant. The positive partial correlation for date of tasseling with mean yield of crosses and the negative partial correlation for date of silking with mean yield of crosses, the other characters remaining constant, are in agreement with the partial correlations within the inbred lines and indicate that a negative relation exists also between number of days from tasseling to silking in the inbred parents and the mean yield of their crosses.

Two significant partial correlations were obtained in Group 2. One of these was between number of nodes per plant (F) and mean yield of crosses (Y) and the other was between yield of the inbred line (X) and the mean yield of crosses, each with the other characters in the group constant. The partial correlation for yield of the inbred line with mean yield of crosses for constant plant height, nodes per plant, and nodes below ear indicates that, when size of plant remains constant, approximately 10 per cent of the variation in the mean yield of crosses is associated with variation in yield of the parent line.

None of the partial correlations for mean yield of crosses and the characters in Group 3 and 5 were significant. Inasmuch as all of those for Group 3 were negative they probably indicate that susceptibility to disease in the parent lines tended to be associated with the lower mean yields of crosses. Inasmuch as all of the coefficients of partial correlation for Group 5 are positive, they probably indicate that large-sized ears in the inbred lines tended to be associated with the higher mean yields of crosses.

PREPOTENCY AMONG THE INBRED LINES

The coefficients of correlation between parents and progeny measure the general tendency of these classes toward resemblance in the characters studied. These correlations, however, fail entirely to show the important variation in prepotency that occurs among the inbred lines. As here used, prepotency denotes the capacity of a parent line to impress upon its F_1 crossed progeny certain characteristics, regardless of whether these characteristics are expressed in the parent or not. Variation in prepotency can be shown only by detailed data on the parents and their crossbred progeny. Such data are given in Tables 15 to 26. These are selected for presentation as characteristic of the experiments as a whole.

The experiment for the comparison of inbred lines in 1926 was conducted on more productive soil than that for the comparison of crosses in 1926. The season of 1927 was so much less favorable for corn production than that of 1926 that the acre yields of many of the crosses grown in 1927 were actually less than the yields of some of the better inbred lines grown in 1926. For these reasons, the data on the inbred parent lines, though comparable inter se are not comparable with the data on the crosses.

PRODUCTIVENESS

The data on the yields of the F_1 crosses in the 1926 and 1927 comparisons of crosses and the yields of the inbred parent lines are shown for the various yield groups in Tables 15 to 19. Because of differences in season and soil productivity these yields are not comparable from table to table.

The crossing-block numbers of the parent lines are shown along the top and left sides of the tables. The yield of each cross is recorded at the intersection of the appropriate row and column. The mean yields of the crosses of each parent line and the yields of the parent lines themselves are recorded in rows and columns along the right and lower margins of the tables.

The correlations between the yields of the inbred parents and the mean yields of their F_1 crosses, as given in Table 13, for the five yield groups in Tables 15 to 19, inclusive, were: 0.67 ± 0.09; 0.64 ± 0.09; 0.25 ± 0.11; 0.41 ± 0.17; and 0.45 ± 0.07. The correlations for Tables 15, 16, and 19 are significant, and those for Tables 17 and 18 are not significant. These correlations indicate a relation between the yields of the parents and the mean yields of their crosses. They do not bring out, however, the way in which certain lines impress upon their crosses a consistency in productiveness.

TABLE 15.—*Yield per row (pounds) of the F_1 crosses between inbred lines from varieties of white corn compared with yields of the parent lines*

[1926 comparison of crosses. P. E. (probable error) of the difference between the yields of any two parent lines, ±0.460; P. E. of the difference between the yields of any two F_1 crosses, ±0.627; P. E. of the difference between means of 9 crosses, ±0.192, and between means of 10 crosses, ±0.182]

No. of parent line	Crossing-block Nos. of parent lines										Mean yield of crosses	Yield of parent [a]
	11	12	13	14	15	16	17	18	19	20		
1	10.87	13.46	9.90	11.75	13.54	11.67	10.85	12.16	11.93	14.61	12.07	------
2	12.31	12.82	13.94	16.67	13.99	12.68	12.44	12.37	13.72	13.42	13.44	6.88
3	9.18	11.79	9.86	11.79	12.90	9.28	11.71	12.21	10.91	12.26	11.19	4.16
4	12.14	13.23	12.88	15.41	14.17	12.06	13.02	11.84	10.92	14.55	13.02	7.24
5	10.04	13.42	11.61	16.13	13.77	10.48	12.79	12.02	11.38	13.64	12.53	7.37
6	10.55	12.00	11.99	14.14	14.61	12.34	13.11	13.40	11.96	13.71	12.78	4.82
7	12.43	13.82	11.36	14.21	13.63	13.87	14.13	12.28	13.10	13.54	13.24	7.87
9	13.10	12.84	12.74	16.02	14.09	13.82	14.09	13.10	14.97	13.26	13.80	7.53
10	10.67	12.50	13.33	15.59	10.94	12.10	12.08	9.71	9.88	11.59	11.84	5.13
Mean yield of crosses	11.25	12.88	11.96	14.63	13.52	12.03	12.69	12.12	12.09	13.40	[b]12.66	------
Yield of parent [a]	5.71	4.77	------	7.89	5.85	5.40	5.59	6.42	5.42	------	------	------

[a] Yields of the parent lines are not comparable with the yields of the crosses.
[b] Mean yield of all crosses in this group.

TABLE 16.—*Yield per row (pounds) of the F_1 crosses between inbred lines from early varieties of yellow corn compared with yields of the parent lines*

[1926 comparison of crosses. P. E. (probable error) of the difference between the yields of any two parent lines, ±0.460; P. E. of the difference between the yields of any two F_1 crosses, ±0.501; P. E. of the difference between means of 9 crosses, ±0.154, and between means of 10 crosses, ±0.146]

No. of parent line	Crossing-block Nos. of parent lines										Mean yield of crosses	Yield of parent [a]
	31	32	33	34	35	36	37	38	39	40		
21	6.50	6.50	10.24	8.21	12.27	7.81	10.78	10.06	8.61	10.02	9.10	2.45
22	11.45	9.33	11.67	10.74	12.46	11.49	11.88	13.54	12.00	10.40	11.50	8.19
24	13.28	11.72	12.01	12.44	13.46	12.58	11.29	13.34	13.23	10.72	12.41	4.45
25	15.12	12.63	14.22	14.43	14.86	13.80	13.74	14.34	14.50	12.88	14.05	8.74
26	13.74	12.47	14.90	14.84	14.38	13.51	14.00	13.52	13.70	13.17	13.82	7.92
27	9.61	6.40	10.92	10.40	9.41	10.77	10.60	10.69	10.14	8.00	9.69	4.33
28	13.34	10.83	12.75	12.23	12.72	14.30	11.40	12.09	13.77	10.57	12.40	5.02
29	13.69	8.97	15.04	13.33	12.84	12.33	14.60	14.87	10.31	10.16	12.61	2.58
30	14.01	10.15	14.64	13.65	12.50	15.02	14.08	12.28	12.60	9.92	12.88	5.33
Mean yield of crosses	12.30	9.89	12.93	12.25	12.77	12.40	12.49	12.75	12.10	10.65	[b]12.05	------
Yield of parent [a]	3.20	1.85	6.63	5.68	9.14	5.85	6.63	7.45	3.09	2.83	------	------

[a] Yields of the parent lines are not comparable with the yields of the crosses.
[b] Mean yield of all crosses in this group.

Each of these tables contains excellent demonstrations of the differences in the ability of different inbred lines consistently to produce high-yielding crosses. In Table 15, inbred lines Nos. 11 to 20 were parents of comparable series of crosses. The crosses of line 14 had the highest mean yield. All crosses yielding 16 pounds or more had line 14 as one parent. A comparison of lines 13 and 14 as parents shows that in every pair of comparable crosses, the one having line 14 as parent yielded more. A similar condition holds when lines 11, 16, and 17 are compared with line 14.

Of the crosses in Table 16, those of line 25 had the highest mean yield. Comparing the individual crosses of line 25 with comparable crosses of lines 21, 22, 24, and 27, the crosses of line 25 were always the highest yielding.

Of the crosses in Table 17 those of line 66 had the highest mean yield. Comparing the crosses of this line with comparable crosses of lines 46, 47, 52, 54, 55, 56, 61, 62, 67, 70, 74, 78, and 80, that with line 66 was the highest yielding in every case.

Now, if it be assumed that the lines listed across the top of Table 17 (41, 42, 43, etc.) were the lines that were being tested, and that the lines listed down the left side of the table were the testers, most of the former lines were used in 28 or 29 comparable crosses. The crosses of line 65 had the highest mean yield. Comparing lines 65 and 63 as parents, there were 28 pairs of comparable crosses, in 27 of which that of line 65 was higher yielding. The yields of these 28 pairs of comparable crosses are shown graphically in Figure 1. Lines 43 and 63 also were used in 28 pairs of comparable crosses, and in 27 of the comparisons the cross of line 43 was the higher yielding.

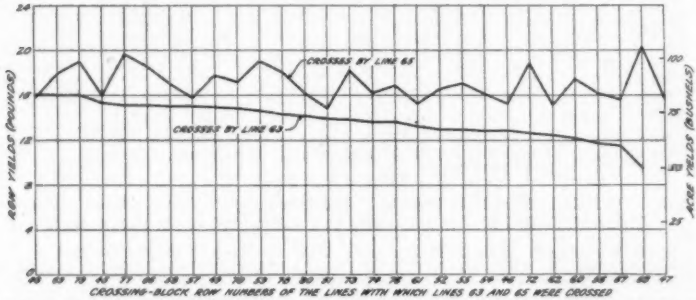
ROW YIELDS (POUNDS)
ACRE YIELDS (BUSHELS)
CROSSES BY LINE 65
CROSSES BY LINE 63
CROSSING-BLOCK ROW NUMBERS OF THE LINES WITH WHICH LINES 63 AND 65 WERE CROSSED

FIGURE 1.—Yields of the comparable F_1 crosses of several inbred lines with line 63 and with line 65

TABLE 17.—*Yield per row (pounds) of the F_1 crosses between inbred lines from the later varieties of yellow corn compared with yields of the parent lines*

[1926 comparison of crosses. P. E. (probable error) of the difference between the yields of any two parent lines, ±0.460; P. E. of the difference between the yields of any two F_1 crosses, ±0.627; P. E. of the difference between means of 10 crosses, ±0.182, and between means of 29 crosses, ±0.107]

No. of parent line	Crossing-block Nos. of parent lines										Mean yield of crosses	Yield of parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	16.38	15.76	16.81	21.42	------	15.33	12.79	15.87	18.59	19.39	16.93	8.50
46	13.31	13.64	15.62	13.77	14.31	12.78	11.77	15.16	11.60	19.28	14.12	7.56
47	13.99	13.37	14.60	13.46	12.66	------	16.14	15.63	15.79	16.78	14.71	5.27
48	14.52	17.60	18.45	10.09	20.74	16.05	15.69	15.73	15.05	15.91	15.98	9.39
49	16.23	19.35	19.02	13.70	16.19	14.86	17.80	17.74	17.08	17.38	16.94	8.91
51	16.61	10.97	13.05	10.94	15.68	13.88	15.71	14.82	16.97	16.89	15.05	7.40
52	13.62	15.14	16.47	14.41	15.92	12.86	13.89	16.49	14.82	15.10	14.87	6.87
54	14.15	16.10	16.67	14.68	14.35	12.83	16.11	15.97	15.98	17.43	15.43	7.64
55	13.81	14.98	15.99	13.80	13.95	12.85	16.33	16.99	16.80	16.68	15.22	5.85
56	13.75	13.19	15.53	------	------	11.69	------	16.09	15.14	15.23	14.37	6.65
57	15.06	17.41	18.01	15.67	------	15.01	17.68	15.70	17.38	17.59	16.61	8.27
58	14.71	16.49	17.04	16.63	15.00	15.04	18.02	17.04	17.91	15.00	16.29	7.22
59	15.44	18.29	19.93	16.30	------	14.60	17.29	19.03	19.15	------	17.50	6.97
60	15.21	16.52	16.43	14.61	17.50	12.07	18.40	17.37	17.61	18.12	16.38	9.84
61	14.80	12.96	16.73	14.67	14.27	13.24	16.75	15.20	14.80	15.05	14.85	5.14
62	13.26	15.85	14.30	14.09	15.23	12.39	16.58	15.11	15.72	14.81	14.73	3.92
66	15.99	17.16	18.30	17.97	19.57	15.07	18.53	18.48	17.19	19.82	17.81	7.36
67	11.83	13.65	15.28	12.44	15.22	11.51	17.82	15.60	13.71	14.13	14.12	11.67
68	11.97	13.11	17.23	16.20	16.48	9.53	18.56	20.34	15.38	15.33	15.41	4.44
69	13.96	16.18	18.29	16.54	18.71	16.04	16.33	17.90	14.51	15.65	16.41	10.26
70	13.64	15.49	18.03	16.02	16.59	14.83	15.98	17.14	15.83	11.72	15.53	8.42
72	12.35	15.47	15.71	15.98	17.28	12.64	16.73	18.76	14.54	16.07	15.55	7.77
73	12.18	18.47	15.43	15.00	------	13.77	16.23	18.15	11.55	13.54	14.92	6.71
74	14.15	16.12	16.90	17.46	17.45	13.61	15.92	16.14	12.61	13.72	15.41	6.09
76	14.39	15.34	16.89	15.71	15.38	13.57	15.68	16.79	18.65	16.39	15.88	6.34
77	17.14	20.44	16.50	18.03	17.54	15.11	17.83	19.58	13.56	18.34	17.41	9.07
78	13.60	13.36	15.81	15.88	16.39	14.25	17.32	17.98	15.40	17.12	15.71	6.66
79	12.92	12.95	15.81	17.05	18.62	15.99	17.49	18.99	14.96	15.06	15.98	------
80	14.70	16.46	17.67	14.73	17.48	14.11	16.93	16.10	16.93	15.71	16.08	8.60
Mean yield of crosses	14.26	15.58	16.81	15.26	16.36	13.77	16.51	16.96	15.70	16.19	[b]15.73	------
Yield of parent [a]	------	------	7.62	1.83	6.84	8.44	9.62	7.08	8.62	8.66	------	------

[a] Yield of the parent lines are not comparable with the yields of the crosses.
[b] Mean yield of all crosses in this group.

Of the crosses in Table 18 those of lines 112 and 107 had the highest mean yields. Comparing the crosses by these two lines with comparable crosses by the other lines, the crosses of line 112 outyielded all of the comparable crosses of line 103, and line 111 outyielded eight of the nine crosses by line 104 and outyielded seven of the eight crosses by line 101 and by line 109. The crosses by line 107 outyielded all comparable crosses by line 104 and outyielded the comparable crosses by line 101, by line 103, and by line 106 in eight out of nine cases.

Among the crosses by 43 parent lines listed at the left of Table 19 the crosses by lines 124, 135, and 146 had the highest mean yields. The crosses by line 135 outyielded all of the comparable crosses by each of 20 of the remaining 42 lines. The crosses by line 124 outyielded all of the comparable crosses by 19 of the remaining 42 lines, except that in two pairs the comparable crosses were tied. The crosses by line 146 outyielded all of the comparable crosses by 17 of the remaining 42 lines.

CHARACTERS OTHER THAN PRODUCTIVENESS

Inspection of the data on all of the characters studied showed differences in prepotency similar to those pointed out for productiveness. These differences in prepotency for various characters occurred more or less equally within all of the different yield groups. This generality of prepotency has been shown in detail sufficiently by the data on productiveness in the different groups. Accordingly, additional data are presented here only on selected characters in the group of late crosses compared in 1926.

Data on the percentage of plants erect at harvest are recorded in Table 20.

TABLE 18.—*Yield per row (pounds) of the F_1 crosses between inbred lines from varieties of white corn compared with yields of the parent lines*

[1927 comparison of crosses. P. E. (probable error) of the difference between the yields of any two parent lines, ±0.460; P. E. of the difference between the yields of any two F_1 crosses, ±0.563; P. E. of the difference between means of 9 crosses, ±0.173, and between means of 10 crosses, ±0.164]

No. of inbred line	Crossing-block Nos. of parent lines											Mean yield of crosses	Yield of parent [a]
	101	102	103	104	105	106	107	109	110	111	112		
101	.....	11.33	11.45	10.60	10.64	10.78	11.33	11.03	11.17	10.97	11.50	11.08	7.17
102	11.33	.....	11.64	12.39	9.54	11.62	12.89	9.25	12.30	13.06	14.54	11.86	5.32
103	11.45	11.64	.....	10.36	11.33	11.67	11.13	11.76	11.40	10.08	11.18	11.20	7.64
104	10.60	12.39	10.36	.....	10.69	10.86	11.87	10.99	11.64	11.31	.....	11.19	7.40
105	10.64	9.54	11.33	10.69	.....	10.50	12.45	10.89	11.91	.....	13.16	11.23	5.11
106	10.78	11.62	11.67	10.86	10.50	.....	13.65	11.35	12.18	10.46	11.88	11.51	6.65
107	11.33	12.89	11.13	11.87	12.45	13.65	.....	12.06	12.87	12.21	12.40	12.29	6.30
109	11.03	9.25	11.76	10.99	10.89	11.35	12.06	.....	12.31	10.87	12.69	11.32	6.18
110	11.17	12.30	11.40	11.64	11.91	12.18	12.87	12.31	.....	12.50	12.57	12.09	6.31
111	10.97	13.06	10.08	11.31	.....	10.46	12.21	10.87	12.50	.....	11.22	11.42	4.26
112	11.50	14.54	11.18	.....	13.16	11.88	12.40	12.69	12.57	11.22	.....	12.35	.....
Mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	[b]11.60	.....

[a] Yields of the parent lines are not comparable with the yields of the crosses.
[b] Mean yield of all crosses in this group.

TABLE 19.—*Yield per row (pounds) of the F_1 crosses between inbred lines from varieties of yellow corn compared with yields of the parent lines*

[1927 comparison of crosses. P. E. (probable error) of the difference between the yields of any two parent lines, ±0.460; P. E. of the difference between the yields of any two F_1 crosses, ±0.617; P. E. of the difference between means of 9 crosses, ±0.190, and between means of 43 crosses, ±0.086]

No. of parent line	Crossing-block Nos. of parent lines									Mean yield of crosses	Yield of parent [a]
	121	140	143	150	153	157	160	168	171		
114	9.11	11.85	9.27	10.97	9.99	8.76	10.57	10.07	9.99	10.06	4.91
116	10.21	10.04	10.34	10.54	8.82	10.10	10.64	8.67	9.22	9.84	5.24
117	8.76	11.26	10.34	10.79	11.54	11.38	9.93	9.48	10.19	10.41	7.34
118	8.54	12.87	10.70	9.59	11.16	9.44	10.18	10.70	9.65	10.31	5.66
119	9.94	11.67	11.21	9.28	10.70	10.52	10.90	11.18	10.69	10.68	9.41
120	10.17	13.06	9.96	11.08	11.13	11.00	11.59	10.24	11.53	11.08	5.71
123	9.51	10.30	10.18	10.66	11.09	9.14	10.12	10.97	11.22	10.35	9.83
124	10.99	12.75	13.43	10.83	12.46	12.69	12.85	12.68	12.02	12.30	9.38
125	11.73	------	11.07	10.89	11.18	9.78	11.77	11.01	9.79	10.90	12.17
126	11.68	13.37	13.18	9.50	12.47	10.62	13.21	11.38	11.26	11.85	15.76
128	11.74	11.86	11.62	11.31	12.56	12.27	12.27	11.13	10.69	11.72	8.48
129	10.16	11.94	10.79	11.68	11.52	11.49	10.44	10.92	11.48	11.16	8.87
130	10.32	11.31	10.37	10.14	10.95	10.83	11.08	11.57	11.63	10.91	2.02
132	9.83	12.44	10.61	10.85	11.39	11.10	11.20	10.71	12.05	11.13	12.04
133	9.00	11.23	8.82	8.57	8.96	10.26	9.72	11.73	10.36	9.85	6.89
135	13.21	12.57	12.34	12.06	12.40	14.04	12.99	10.99	11.29	12.43	9.52
136	12.43	10.41	11.54	11.16	13.20	11.41	12.14	12.92	9.67	11.65	7.99
139	12.18	9.81	11.53	11.76	11.43	12.25	12.10	10.29	11.18	11.39	11.21
141	11.80	11.99	12.79	9.31	11.45	10.54	11.55	12.07	9.02	11.17	8.72
142	11.83	11.64	11.38	12.43	11.99	11.63	11.72	12.21	11.06	11.76	6.82
144	12.07	10.32	10.51	11.31	11.20	11.53	11.26	10.98	9.66	10.98	9.43
146	11.54	13.87	13.26	12.49	11.84	10.34	13.72	10.86	12.50	12.27	4.72
147	9.85	10.38	8.13	10.16	10.82	7.90	10.72	10.30	9.88	9.79	4.83
149	10.68	12.02	9.77	9.02	9.09	10.87	10.56	11.01	10.46	10.39	9.53
151	------	------	9.72	10.90	10.60	9.02	11.18	9.65	10.05	10.16	7.92
154	10.36	13.05	11.06	11.81	11.31	10.83	11.23	12.54	10.34	11.39	8.42
155	12.67	12.78	9.55	10.58	11.59	11.46	10.44	11.25	10.38	11.19	7.69
156	9.76	10.12	8.98	10.83	10.44	12.29	11.05	10.00	10.91	10.49	6.88
158	9.73	11.97	10.95	12.00	9.12	8.74	10.71	10.16	10.10	10.39	6.28
159	9.44	9.37	8.96	8.27	8.93	8.62	6.57	8.58	9.11	8.65	5.13
161	10.09	12.81	11.16	10.83	12.23	9.86	11.24	9.89	11.66	11.09	8.51
162	10.76	9.74	8.49	10.10	9.26	10.50	8.50	8.93	10.39	9.63	8.38
164	9.17	13.19	9.13	11.26	10.83	9.54	10.84	9.30	9.48	10.30	3.71
165	9.25	11.69	9.53	9.68	9.62	9.36	9.52	9.24	9.83	9.75	6.21
166	10.68	10.26	11.55	10.63	10.69	9.50	10.88	8.90	9.61	10.30	10.74
167	10.22	12.48	10.41	9.82	10.62	9.49	9.80	9.24	10.47	10.28	2.14
169	10.88	12.70	10.94	9.64	10.65	11.16	11.21	9.50	11.57	10.92	9.48
170	8.97	9.22	9.42	9.54	7.31	10.01	10.46	7.12	9.05	9.01	4.83
172	9.93	8.90	10.20	11.06	10.05	10.95	10.87	11.15	9.35	10.27	5.20
173	9.00	8.63	9.53	9.66	8.96	8.65	10.78	8.81	7.58	9.07	2.80
174	9.80	11.64	11.67	11.33	11.45	10.10	10.63	10.61	10.03	10.81	------
175	9.54	------	9.70	10.28	11.06	8.88	10.36	8.96	10.36	9.89	------
176	8.51	10.98	9.96	9.97	9.86	9.49	9.87	9.81	10.51	9.88	------
Mean yield of crosses	10.38	11.46	10.56	10.57	10.79	10.43	10.92	10.41	10.40	[b]10.65	------
Yield of parent [a]	8.48	9.38	11.58	8.98	5.28	6.51	9.15	5.56	5.21	------	------

[a] Yields of the parent lines are not comparable with the yields of the crosses.
[b] Mean yield of all crosses in this group.

The coefficient of correlation for the percentage of plants erect at harvest, between the parent lines and the means of their crossbred progeny, from the data in Table 20, was 0.88 ± 0.03 (Table 13). This is a very high correlation and indicates that about 77 per cent of the variance among the mean percentages of erect plants in the crosses was associated with variation in percentages of erect plants in the parent lines. All of the crosses of some inbred lines had high percentages of erect plants, whereas all of the crosses of other lines had low percentages of erect plants. Thus, all of the crosses by line 46 had higher percentages of erect plants than the comparable crosses by line 47. A similar condition exists as between lines 57 and 58 and lines 62 and 60. Lines 63 and 65 were used in 28 comparable pairs of crosses. In 27 of these the cross with line 65 as one parent

had a higher percentage of erect plants than that with line 63 as a parent. The data on the percentage of erect plants in these two lines are shown graphically in Figure 2.

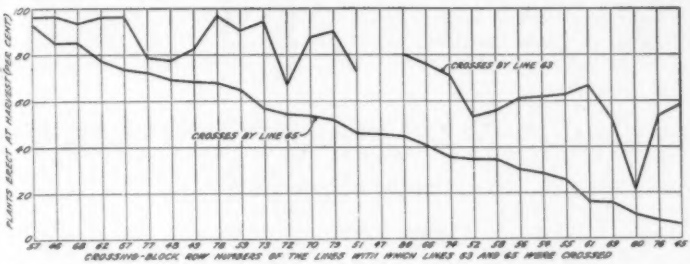
PLANTS ERECT AT HARVEST(PER CENT)
100
80
60
40
20
0
CROSSES BY LINE 63
CROSSES BY LINE 65
53 46 68 62 57 77 45 49 78 59 73 72 70 79 51 47 80 66 74 52 58 56 54 55 61 69 60 76 65
CROSSING-BLOCK ROW NUMBERS OF THE LINES WITH WHICH LINES 63 AND 65 WERE CROSSED

FIGURE 2.—Percentages of plants erect at harvest in the comparable crosses of several inbred lines with line 63 and with line 65

TABLE 20.—*Percentage of plants erect at harvest in the F_1 crosses between inbred lines from the later varieties of yellow corn compared with the parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Percentage erect in parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	89.6	63.4	32.9	77.9	-------	58.0	50.0	6.3	64.6	72.2	57.2	49.1
46	96.6	92.3	82.5	92.0	70.5	96.7	95.1	85.2	68.9	96.4	87.6	92.1
47	28.9	13.8	42.5	80.9	42.2	-------	19.6	45.3	45.8	72.6	43.5	9.9
48	77.3	50.0	71.8	70.4	100	77.4	60.9	69.2	76.5	72.2	72.6	61.2
49	99.6	97.5	75.2	100	100	82.7	80.8	68.3	83.8	97.8	88.6	55.0
51	67.9	53.5	74.6	81.6	97.7	72.6	56.8	45.9	64.7	80.5	69.6	63.2
52	80.2	57.4	49.0	50.4	81.5	53.1	44.9	34.7	35.5	69.5	55.6	15.2
54	58.7	46.3	15.5	66.5	44.4	61.3	36.6	28.3	56.7	69.9	48.4	8.5
55	77.0	66.4	39.2	61.6	74.5	62.5	5.4	25.7	50.6	79.2	54.2	12.5
56	78.4	58.3	66.0	-------	-------	60.9	-------	30.1	67.8	73.8	62.2	33.9
57	92.0	83.8	94.5	96.6	-------	96.9	80.5	93.0	94.7	98.5	92.3	93.6
58	75.0	42.5	23.3	54.0	68.6	55.6	30.0	34.6	33.8	69.0	48.6	14.4
59	83.7	77.7	74.8	97.7	-------	90.6	63.8	64.6	65.5	-------	77.3	90.2
60	76.6	41.1	30.3	68.8	48.9	21.1	43.7	10.2	41.2	73.7	45.6	52.3
61	66.1	44.3	36.8	41.7	51.1	66.2	49.4	16.0	42.4	67.6	48.2	0.0
62	94.0	95.3	86.1	98.0	99.2	96.4	90.9	77.4	97.3	97.2	93.2	91.3
66	64.8	56.2	65.0	56.3	93.8	75.9	75.6	40.3	78.0	73.5	67.9	1.6
67	95.5	85.3	61.4	83.8	100	96.2	72.1	73.8	73.4	85.4	82.7	80.9
68	93.5	78.0	67.3	97.2	98.1	93.2	86.2	84.8	98.6	77.0	87.4	100
69	84.3	55.4	54.2	56.2	84.0	51.5	52.6	15.7	56.1	65.4	57.5	14.2
70	94.0	89.1	46.5	89.1	83.0	87.9	84.8	53.4	93.7	86.9	80.8	78.2
72	92.1	89.5	62.7	73.5	96.4	67.3	65.0	54.0	62.8	86.7	75.0	65.7
73	99.1	73.8	84.2	100	-------	94.4	83.9	56.5	89.8	96.0	86.4	100
74	76.1	86.7	52.0	80.9	91.7	70.9	38.4	35.4	62.9	89.5	68.4	36.2
76	53.9	49.0	25.3	70.5	79.2	53.5	56.2	8.0	40.6	65.2	50.1	8.3
77	95.0	81.4	62.4	82.8	92.8	78.3	69.5	72.3	76.0	92.8	80.3	88.4
78	95.4	85.4	84.9	97.6	98.5	97.0	74.1	67.8	81.0	96.8	87.8	99.1
79	90.3	84.0	64.8	95.5	72.2	90.0	51.8	51.6	81.3	82.6	76.4	-------
80	84.4	82.0	58.9	85.4	85.7	80.2	54.5	44.6	78.6	86.0	74.0	44.3
Mean of crosses	81.4	68.3	58.1	78.8	81.4	74.6	59.8	48.0	67.7	81.2	[b] 69.7	-------
Percentage erect in parent [a]	-------	-------	27.4	78.7	94.8	61.8	37.7	1.5	60.5	85.3	-------	-------

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean percentage erect for all crosses in this group.

Data on the date of silking, recorded as the number of days after June 30, are shown in Table 21. The coefficient of correlation for the date of silking between the parent lines and the means of the crossbred progeny was 0.59 ± 0.07. These data again illustrate the degree to which inbred lines may influence their F_1 crosses. For example, in the 28 pairs of comparable crosses by lines 71 and 63 the crosses by line 71 silked later in 27 pairs, and in 1 pair the comparable crosses silked on the same day.

TABLE 21.—*Date of silking (days after June 30) for the F_1 crosses between inbred lines from the later varieties of yellow corn compared with parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Date of silking for parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	23.5	24.5	24.5	26.0	------	23.5	24.0	24.5	28.0	23.5	24.7	32.3
46	25.0	23.5	24.5	27.0	26.0	23.5	22.5	25.0	30.0	24.5	25.2	34.3
47	26.0	24.5	25.5	26.5	26.0	------	24.5	25.5	26.5	25.5	25.6	30.3
48	23.0	25.0	24.0	25.0	24.0	25.0	23.5	23.0	29.0	25.0	24.6	35.3
49	25.0	23.5	23.0	26.0	25.5	24.0	22.5	24.0	27.5	25.0	24.6	34.7
51	25.0	24.0	25.5	28.0	24.5	24.5	26.0	27.5	30.0	28.0	26.3	34.3
52	26.0	26.5	28.0	28.0	27.0	26.0	27.0	28.5	27.0	26.0	27.0	38.3
54	25.0	23.5	25.5	22.5	24.0	24.0	26.0	26.0	25.5	26.0	24.8	31.0
55	23.0	25.0	24.5	26.5	24.5	24.0	26.0	27.0	25.0	25.0	25.0	31.3
56	24.5	23.0	24.5	------	------	23.5	------	25.0	27.0	25.0	24.6	29.3
57	25.0	24.0	25.5	23.0	------	23.5	26.5	24.0	25.5	27.0	24.9	31.7
58	24.0	26.0	27.0	26.5	25.0	24.5	27.5	28.0	27.0	27.5	26.3	30.3
59	26.0	25.0	28.0	25.5	------	24.5	26.0	27.0	27.0	------	26.1	30.0
60	26.0	26.0	30.5	29.0	29.0	24.0	30.5	32.0	28.5	29.0	28.4	32.0
61	27.0	29.0	28.0	27.0	28.0	25.5	29.5	30.5	28.0	27.0	28.0	36.3
62	23.5	22.5	28.0	23.5	23.5	23.5	24.5	27.5	26.5	26.0	24.9	30.7
66	27.0	25.0	30.5	28.0	26.0	24.5	27.5	28.5	28.0	29.5	27.4	38.3
67	29.0	24.5	30.5	27.0	27.0	27.5	29.0	29.5	31.0	27.0	28.2	33.0
68	26.0	24.5	30.0	24.0	26.0	25.0	26.0	29.0	28.0	29.0	26.8	34.3
69	28.0	26.0	31.0	29.0	28.5	26.0	27.5	30.0	29.0	29.0	28.4	35.7
70	23.5	23.5	26.0	27.0	24.0	23.0	24.5	26.0	26.0	29.0	25.2	34.3
72	27.5	26.5	29.5	27.0	27.5	29.0	29.0	28.0	30.0	30.5	28.4	35.0
73	30.5	28.0	30.5	29.0	------	27.0	31.0	30.5	33.5	33.0	30.3	43.0
74	30.0	27.0	33.0	30.0	29.5	28.0	28.5	34.0	34.5	33.0	30.8	38.3
76	29.5	26.5	30.0	30.0	27.0	25.0	28.0	30.5	30.5	30.5	28.8	39.0
77	30.0	26.0	33.0	29.0	28.0	27.5	28.0	31.0	27.5	29.0	28.9	38.3
78	27.0	24.0	29.0	27.5	25.0	23.5	23.5	26.5	26.5	28.0	26.0	36.7
79	29.0	28.5	31.0	28.5	30.0	27.0	29.0	30.5	33.0	33.0	30.0	------
80	24.5	23.0	28.0	25.0	26.0	24.5	23.5	27.5	26.0	27.0	25.5	30.7
Mean of crosses	26.2	25.1	27.9	26.8	26.3	25.0	26.5	27.8	28.3	27.8	[b] 26.8	------
Date of silking for parent [a]	------	------	36.3	33.0	35.0	30.3	32.3	38.0	40.0	39.0	------	------

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean date of silking for all crosses in this group.

Data on the number of days between tasseling and silking are recorded in Table 22. Protandry is indicated by positive values and protogyny by negative values. The coefficient of correlation between inbred parents and the mean value for their crossbred progeny for the data in Table 22 was 0.66 ± 0.06. (This coefficient is not shown in Table 13.)

TABLE 22.—*Days from tasseling to silking in the F_1 crosses between inbred lines from the later varieties of yellow corn compared with the parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Value for parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	−1.0	2.5	1.0	1.0		0.5	1.0	1.0	1.5	1.5	1.0	−0.4
46	.5	1.5	1.0	.5	1.5	0	0	2.0	2.0	1.0	1.0	−.2
47	2.0	2.5	1.0	2.0	3.0		2.0	2.5	2.0	2.0	2.1	1.6
48	−2.0	2.0	.5	1.0	1.0	1.5	.5	0	.5	2.0	.7	2.0
49	−.5	1.5	0	−1.0	.5	.5	1.0	1.0	.5	.5	.4	3.7
51	.5	2.0	1.0	2.5	1.0	1.5	2.5	3.0	1.0	2.0	1.7	3.3
52	0	3.5	2.5	1.0	1.5	2.0	1.5	2.5	1.5	1.0	1.7	1.6
54	.5	1.5	1.5	.5	1.0	1.0	1.0	3.0	.5	2.5	1.3	.3
55	.5	3.5	.5	2.0	1.5	1.0	3.0	3.0	1.0	1.5	1.8	−.7
56	.5	1.0	.5			.5		1.0	3.0	1.0	1.1	−.7
57	0	1.0	.5	0		.5	1.0	1.0	−1.0	0	.3	.4
58	−1.0	2.5	2.0	−.5	1.5	1.5	3.0	3.0	2.5	2.5	1.7	.3
59	1.0	2.0	3.0	1.5		2.5	1.5	2.5	1.5		1.9	2.0
60	1.0	3.0	1.5	2.5	2.0	1.0	3.5	3.0	2.0	3.0	2.2	3.0
61	1.0	3.5	.5	1.5	.5	0	3.5	3.0	−.5	1.0	1.4	3.6
62	.5	2.0	1.0	.5	1.5	1.5	2.5	2.5	3.0	2.5	1.8	1.7
66	2.5	2.5	2.0	1.0	1.5	1.5	2.0	2.0	2.0	2.5	2.0	3.3
67	1.0	2.5	.5	1.5	2.0	2.5	5.5	3.5	5.0	2.5	2.6	3.0
68	3.0	3.5	3.5	1.5	3.0	2.0	3.0	5.5	5.5	5.0	3.5	5.6
69	2.5	.5	2.0	−.5	1.5	1.0	1.5	2.5	1.0	2.0	1.4	1.0
70	.5	3.0	0	3.0	1.0	1.5	2.5	3.0	2.5	4.5	2.2	3.3
72	3.5	5.5	4.0	4.0	3.5	4.5	6.0	4.0	6.0	5.5	4.6	5.7
73	0	4.0	5.0	1.5		3.5	3.5	1.5	2.5	3.0	2.7	6.7
74	1.5	3.5	4.0	1.0	3.0	2.0	4.0	3.5	4.0	4.0	3.0	3.3
76	1.5	4.5	1.5	1.0	3.0	2.0	4.0	4.5	4.5	4.0	3.0	4.3
77	1.0	1.5	2.0	−.5	1.5	1.0	2.0	1.5	1.0	2.5	1.4	2.0
78	0	0	2.0	0	1.0	1.5	.5	1.5	1.5	2.5	1.0	.7
79	2.5	5.0	4.0	3.0	3.0	3.5	4.5	3.5	5.0	4.0	3.8	
80	1.5	2.5	3.0	2.0	2.5	2.0	2.0	3.0	2.5	3.5	2.4	4.0
Mean of crosses	.8	2.5	1.8	1.2	1.8	1.6	2.4	2.5	2.2	2.5	[b]2.0	
Value for parent [a]			3.0	−2.0	2.0	.6	.6	4.3	3.7	3.0		

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean number of days from tasseling to silking for all crosses in this group.

Here, too, different inbred lines transmitted very definite tendencies to their F_1 crosses. The mean number of days from tasseling to silking for the crosses by line 41 was 0.8. For those by line 42 the mean was 2.5. In 25 of the 29 pairs of comparable crosses of which these two inbred lines were parents, the cross by line 42 required more days from tasseling to silking than did the comparable cross by line 41; in three pairs the crosses were tied; and in only one pair did the cross by line 41 require more days from tasseling to silking than the cross by line 42. An interesting example of a possible effect of the selection within selfed lines is the number of lines and crosses which are protogynous. Of the progenies listed in Table 22, 5 of the inbred lines and 10 of the F_1 crosses silked before they tasseled. The general condition among the parent varieties grown in the locality where these data were obtained is for the plants to begin shedding pollen from one to three days before silks appear. It is possible that in selecting the inbred lines there has been an unconscious tendency toward relatively earlier silking plants, as these are the most convenient for self-pollinating. This may have been a factor in obtaining the protogynous lines.

TABLE 23.—*Plant height (in feet) of the F_1 crosses between inbred lines from the later varieties of yellow corn compared with the parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Plant height of parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	7.25	8.00	8.25	8.00	-------	7.50	8.00	8.50	9.00	8.25	8.08	5.00
46	7.25	9.00	8.25	8.25	8.50	8.00	8.75	9.00	9.25	8.25	8.45	7.67
47	7.00	8.00	8.25	7.75	8.00	-------	8.00	9.00	9.00	8.75	8.19	6.50
48	6.00	7.50	8.00	8.00	7.50	6.75	7.75	8.50	8.00	7.50	7.55	7.17
49	7.50	8.00	8.25	8.00	8.00	7.75	8.25	8.50	9.00	8.25	8.15	7.00
51	7.75	8.25	8.50	8.25	8.00	8.00	9.00	9.00	9.25	8.75	8.48	7.17
52	7.00	8.50	8.50	7.75	8.25	7.75	8.50	9.50	8.50	8.25	8.25	6.67
54	6.25	8.00	8.00	7.25	7.00	7.00	8.00	8.50	8.00	8.25	7.62	5.67
55	6.25	8.00	7.75	7.00	7.75	7.00	8.00	8.50	8.25	8.00	7.65	6.17
56	6.50	7.25	7.50	-------	-------	7.00	-------	8.00	8.50	7.75	7.50	6.33
57	6.50	8.00	7.50	7.50	-------	7.75	7.75	7.50	8.25	8.00	7.64	8.50
58	7.00	8.50	7.75	8.00	8.00	7.50	8.50	9.00	9.00	8.50	8.18	6.17
59	7.00	7.75	8.00	7.75	-------	7.00	7.75	9.00	9.00	-------	7.91	6.50
60	7.00	8.25	8.25	7.50	8.00	7.00	8.75	8.50	8.50	8.25	8.00	6.83
61	7.25	8.00	8.00	7.25	8.25	7.00	8.25	8.00	8.75	8.25	7.90	6.00
62	6.75	7.75	7.75	7.50	7.75	7.00	7.50	7.75	8.50	8.00	7.62	6.00
66	7.50	8.25	8.75	8.25	8.00	7.25	8.25	8.50	8.50	8.00	8.12	6.33
67	6.25	8.25	7.50	8.00	8.00	8.75	8.50	8.50	8.50	7.50	8.00	7.00
68	5.75	8.00	7.75	8.25	7.75	7.25	8.25	8.50	8.50	7.50	7.75	5.67
69	6.50	8.00	7.75	8.25	8.00	7.75	8.25	8.50	8.50	8.50	8.00	7.33
70	6.25	8.25	8.00	8.25	8.00	7.00	8.25	8.25	8.00	7.75	7.80	6.67
72	6.50	8.75	8.75	8.50	8.00	7.50	9.00	9.00	7.75	8.25	8.20	7.43
73	7.50	8.50	8.00	8.25	-------	7.75	9.25	9.25	9.00	8.50	8.44	7.33
74	7.00	8.25	8.00	8.75	8.50	7.50	8.50	8.75	8.50	7.75	8.15	7.17
76	7.00	8.00	7.50	8.25	8.25	7.25	8.25	8.25	8.50	8.00	7.92	7.67
77	7.50	9.00	8.50	8.75	8.75	7.50	9.50	9.75	9.00	8.25	8.65	8.33
78	6.50	8.25	7.75	8.25	8.00	7.50	8.50	9.25	9.00	8.00	8.10	7.00
79	7.75	8.50	8.00	8.75	9.50	8.00	9.00	9.25	9.50	8.50	8.68	-------
80	6.75	8.25	7.75	8.00	8.00	7.75	8.00	8.25	8.50	7.50	7.90	7.17
Mean of crosses	6.86	8.17	8.02	8.01	8.07	7.46	8.37	8.65	8.64	8.11	[b] 8.03	-------
Plant height of parent [a]	-------	-------	7.00	7.00	7.00	5.33	7.83	7.67	7.33	7.33	-------	-------

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean plant height for all crosses in this group.

The data on plant height are given in Table 23. The coefficient of correlation between parents and the means of their crosses was 0.53 ± 0.08. Of the various lines shown, line 41 was outstanding in that all of its F_1 crosses were short. It is possible that this line was homozygous for dominant genes determining short stature. The lines other than 41 differed but little in the mean heights of their F_1 crosses. Even so, there were consistent tendencies in the crosses by certain lines. As an example, the mean height of crosses for line 64 was 0.91 foot greater than that of line 63. These two lines were used in 27 pairs of comparable crosses, and in 25 pairs the cross by line 64 was the taller.

The data on percentage of ears moldy are recorded in Table 24. The parent progeny correlation for this character was only 0.25 ± 0.11 and can not be considered significant. The detailed data, however, show that the crosses by different inbred lines exhibited wide differences and very definite tendencies in regard to the percentage of moldy ears in the harvested crop. Nearly all of the crosses by some lines had a high percentage of moldy ears, whereas in others the per-

centage was low. In the 24 pairs of comparable crosses by line 53 and by line 75, all of the crosses by line 53 had lower percentages of moldy ears. In the 24 pairs of comparable crosses by line 53 and by line 43, 23 of the crosses by line 53 had the lower percentages of moldy ears.

TABLE 24.—*Percentage of ears moldy in the F_1 crosses between inbred lines from the later varieties of yellow corn compared with the parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Percentage of moldy ears in parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	15.7	7.7	23.9	8.0	-------	15.1	0.0	32.3	12.3	5.9	13.4	26.4
46	7.0	14.8	8.2	5.9	3.2	14.0	8.3	6.8	4.7	16.9	9.0	5.5
47	0	14.5	22.4	4.0	6.7	-------	8.6	7.2	4.0	13.8	9.0	24.3
48	17.3	6.0	21.4	12.5	4.5	25.6	21.9	9.2	12.9	36.0	16.7	40.5
49	4.8	6.9	9.6	5.3	7.8	15.5	9.1	8.3	6.2	17.8	9.1	22.8
51	6.0	8.1	11.3	8.3	3.0	12.4	13.0	17.9	13.1	12.0	10.5	36.8
52	11.5	7.2	17.7	7.1	8.9	18.1	7.9	10.5	9.9	21.1	12.0	21.3
54	7.6	6.6	31.0	7.5	1.9	13.1	10.3	11.1	8.4	14.5	11.2	22.6
55	26.5	9.9	27.0	7.4	19.4	24.1	6.8	19.8	12.3	21.1	17.4	30.4
56	3.7	15.3	11.2	-------	-------	9.0	-------	9.9	4.2	6.7	8.6	26.4
57	5.0	6.8	8.6	8.5	-------	11.5	8.4	18.6	3.7	12.4	9.3	7.3
58	4.5	7.7	17.5	2.8	7.0	6.4	4.2	5.8	4.2	11.2	7.1	73.4
59	7.9	3.5	4.8	7.0	-------	11.5	9.8	6.6	4.5	-------	7.0	31.9
60	5.7	6.8	11.1	12.2	5.7	19.0	3.0	10.4	7.6	10.5	9.2	30.1
61	3.1	10.3	8.7	3.0	9.0	10.0	7.6	7.0	6.3	16.0	8.1	26.9
62	7.1	8.3	12.1	6.3	2.4	12.3	3.3	7.4	7.1	4.5	7.1	26.4
66	18.7	14.0	12.7	8.4	5.4	12.2	17.9	13.8	14.7	38.4	15.6	26.7
67	9.2	7.9	22.4	16.4	7.7	15.2	5.8	14.1	11.3	22.6	13.3	12.7
68	8.0	9.0	19.6	4.6	4.8	6.8	2.7	4.3	6.1	9.8	7.6	13.1
69	6.7	14.9	22.5	14.5	13.1	24.1	11.8	17.8	14.3	26.7	16.6	38.5
70	19.2	9.5	27.7	13.3	2.7	20.8	18.6	23.8	11.1	29.5	17.6	23.9
72	6.5	9.4	24.9	9.8	3.8	16.0	9.1	8.0	8.6	18.7	11.5	17.5
73	3.1	10.2	15.1	9.6	-------	5.9	4.0	3.5	4.2	12.4	7.6	19.1
74	11.7	9.6	24.4	4.6	8.2	14.2	11.4	8.5	9.7	35.4	13.8	34.8
76	7.5	12.8	26.9	7.4	5.0	16.7	8.2	7.8	3.5	14.4	11.0	14.6
77	12.6	16.2	42.2	15.5	8.6	22.9	9.8	12.6	10.9	25.7	17.7	26.2
78	4.8	5.4	16.8	6.7	7.4	5.7	11.2	8.3	8.7	11.8	8.7	3.1
79	10.1	10.1	13.0	4.7	0	6.7	10.1	5.5	7.9	23.4	9.2	-------
80	9.7	8.0	10.8	8.6	5.6	14.9	16.2	10.2	9.7	20.4	11.4	25.6
Mean of crosses	9.0	9.6	18.1	8.2	6.3	14.3	9.2	11.3	8.3	18.2	[b] 11.3	-------
Percentage of moldy ears for parent [a]	-------	-------	9.0	9.0	7.7	25.6	23.2	18.4	14.4	64.5	-------	-------

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean percentage of ears moldy for all crosses in this group.

The data in this table afford good illustrations of how certain inbred lines may transmit uniformly to their offspring, characters that they do not themselves express. For example, line 58 had the highest percentage of moldy ears (73.4), and yet the mean percentage of moldy ears for the crosses by this line was lower than the mean for comparable crosses by any other line except those by line 59. Moreover, all of the individual crosses by line 58 were low in percentage of ears moldy, with the exception of that with line 43.

TABLE 25.—*Ear-shape index (diameter÷length) for the F_1 crosses between inbred lines from the later varieties of yellow corn compared with the parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Ear-shape index of parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	0.207	0.218	0.203	0.204	------	0.240	0.163	0.187	0.224	0.233	0.209	0.178
46	.228	.232	.210	.226	0.260	.261	.195	.214	.238	.242	.231	.270
47	.240	.270	.222	.239	.258	------	.201	.200	.261	.238	.236	.296
48	.227	.221	.200	.230	.248	.254	.196	.187	.242	.234	.224	.221
49	.225	.246	.230	.219	.244	.269	.212	.198	.269	.240	.235	.298
51	.241	.261	.239	.237	.258	.269	.220	.224	.277	.257	.248	.296
52	.243	.244	.220	.223	.228	.261	.212	.203	.274	.253	.236	.268
54	.229	.238	.230	.224	.252	.280	.224	.200	.254	.239	.237	.255
55	.253	.276	.252	.256	.274	.312	.234	.222	.282	.268	.263	.377
56	.242	.253	.219	------	------	.295	------	.197	.256	.266	.247	.267
57	.265	.267	.244	.249	------	.259	.217	.292	.274	.269	.260	.354
58	.250	.251	.234	.252	.262	.282	.215	.202	.264	.264	.248	.328
59	.258	.243	.211	.244	------	.269	.207	.193	.251	------	.234	.272
60	.236	.275	.241	.249	.272	.275	.217	.219	.257	.246	.249	.293
61	.205	.220	.204	.197	.221	.245	.185	.187	.250	.232	.215	.270
62	.275	.269	.270	.253	.300	.326	.237	.235	.296	.274	.274	.305
66	.239	.240	.224	.246	.263	.289	.225	.207	.287	.289	.251	.335
67	.208	.219	.210	.209	.230	.227	.168	.178	.224	.228	.210	.230
68	.227	.235	.204	.215	.235	.260	.188	.180	.244	.235	.222	.242
69	.253	.267	.245	.243	.270	.291	.225	.232	.279	.260	.256	.273
70	.262	.266	.223	.243	.263	.299	.209	.208	.266	.268	.251	.288
72	.253	.285	.262	.256	.296	.308	.236	.219	.290	.300	.270	.337
73	.208	.249	.247	.258	------	.320	.240	.239	.315	.269	.267	.367
74	.231	.241	.217	.224	.223	.240	.218	.194	.279	.274	.234	.274
76	.283	.266	.233	.255	.271	.321	.219	.211	.271	.251	.258	.284
77	.262	.267	.241	.252	.267	.293	.221	.209	.266	.264	.254	.313
78	.222	.242	.218	.207	.228	.256	.183	.183	.239	.224	.220	.259
79	.254	.255	.215	.236	.222	.246	.197	.188	.267	.247	.233	------
80	.239	.239	.224	.240	.230	.266	.215	.210	.263	.254	.238	.279
Mean of crosses	.242	.250	.227	.235	.253	.275	.210	.208	.264	.254	[b] .242	------
Ear-shape index of parent	------	------	.237	.240	.338	.360	.207	.199	.305	.286	------	------

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean ear-shape index for all crosses in this group.

The data on ear-shape index are shown in Table 25. The correlation between parent and mean of crossbred progeny was 0.85 ± 0.03. Ear-shape index was obtained by dividing the mean ear diameter by the mean ear length. A large index indicates an ear whose diameter was large relative to its length, whereas a small one indicates a relatively long slender ear. The index means for the crosses by various inbred lines ranged from 0.275 for line 63 to 0.208 for line 65. The data in Table 1 show that most of this difference was due to the difference in ear length. The mean ear length for the crosses by line 65 was 5 cm. greater than that for the crosses by line 63, whereas the mean ear diameter of the crosses by line 63 was only 0.15 cm. greater than that of the crosses by line 65.

The data on the mean number of kernel rows per ear are recorded in Table 26. The correlation between the parent and the mean of crossbred progeny was 0.88 ± 0.03. The correlations for this character were uniformly high in all of the three yield groups for which it was computed. (Table 13.) The mean number of kernel rows per ear for the individual crosses listed in Table 26 ranged from 12.1 to 21.7. The means for the crosses by various inbred lines ranged from 14.0 to 18.8. The different inbred lines exercised very definite effects on their crosses. Line 64 produced crosses with relatively low num-

bers of kernel rows per ear, whereas line 63 produced crosses with relatively high numbers of kernel rows per ear. These two inbred lines were used in 27 pairs of comparable crosses, and in every pair the cross by line 63 had a higher number of kernel rows per ear than that by line 64. The numbers of kernel rows for these 27 pairs of comparable crosses and for the parent lines 63 and 64 are shown graphically in Figure 3.

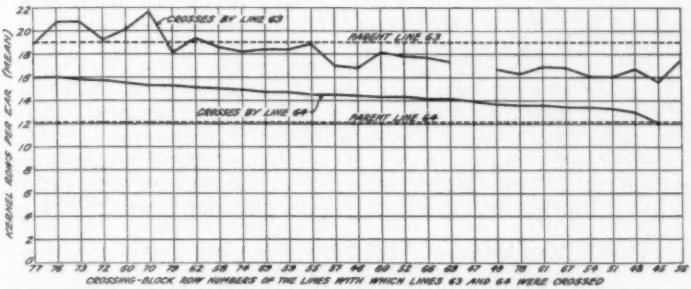
CROSSES BY LINE 63
PARENT LINE 63
CROSSES BY LINE 64
PARENT LINE 64
KERNEL ROWS PER EAR (MEAN)
CROSSING-BLOCK ROW NUMBERS OF THE LINES WITH WHICH LINES 63 AND 64 WERE CROSSED

FIGURE 3.—Number of kernel rows per ear in the comparable crosses of several inbred lines with line 63 and with line 64, and the numbers of kernel rows in the parents

TABLE 26.—*Mean number of kernel rows per ear for the F_1 crosses between inbred lines from the later varieties of yellow corn compared with the parent lines*

[1926 comparison of crosses]

No. of parent line	Crossing-block Nos. of parent lines										Mean of crosses	Kernel rows of parent [a]
	41	42	43	50	53	63	64	65	71	75		
45	15.3	13.4	13.5	13.8	.....	15.6	12.1	13.2	14.5	14.3	14.0	10.6
46	16.1	15.9	16.6	16.5	15.8	16.8	14.4	15.3	16.9	16.2	16.0	16.0
47	16.5	16.0	16.2	15.4	16.5	.....	13.9	15.9	16.9	16.0	15.9	13.9
48	15.7	15.5	14.5	14.6	15.4	16.7	13.0	14.0	15.9	14.0	14.9	12.4
49	15.5	15.1	15.6	14.5	15.2	16.7	13.7	14.8	16.2	15.2	15.2	14.7
51	15.7	14.8	15.6	14.8	14.0	16.0	13.3	14.3	15.7	15.2	14.9	13.8
52	16.8	16.0	16.6	15.8	16.1	17.8	14.3	15.9	17.5	16.9	16.4	14.3
54	15.6	15.1	15.8	15.4	14.7	16.1	13.4	14.3	15.3	14.9	15.1	12.9
55	17.6	16.3	18.1	15.2	16.4	18.9	14.5	16.7	17.6	17.8	16.9	17.5
56	16.1	15.8	16.6	.....	.....	17.5	.....	15.0	17.8	16.6	16.5	15.5
57	16.6	17.4	16.8	15.7	.....	17.0	14.5	19.0	17.5	16.5	16.8	16.4
58	18.3	16.4	17.3	17.9	16.1	18.6	15.0	16.8	17.6	17.5	17.2	16.4
59	19.3	17.9	18.5	16.5	.....	18.4	14.7	16.0	18.0	.....	17.4	16.0
60	17.4	17.4	17.6	17.7	16.9	20.1	15.5	16.4	18.6	16.3	17.4	17.4
61	15.5	15.7	16.1	15.1	13.8	16.9	13.6	14.6	16.8	15.5	15.4	12.7
62	17.9	16.6	17.0	17.0	17.1	19.4	15.1	17.0	18.2	16.7	17.2	16.8
66	16.3	16.5	16.5	15.8	15.6	17.7	14.1	15.2	17.1	15.9	16.1	16.7
67	15.7	16.0	16.6	16.3	14.7	16.8	13.4	15.2	16.1	15.0	15.6	13.7
68	16.0	14.9	16.4	14.9	14.9	17.3	14.1	15.9	16.3	15.1	15.6	14.2
69	16.8	16.1	17.3	16.6	16.4	18.4	14.7	15.1	16.8	16.5	16.5	15.5
70	19.6	18.9	19.3	18.9	18.9	21.7	15.3	17.5	18.7	18.8	18.8	20.4
72	17.9	17.4	18.5	17.9	17.3	19.2	15.7	17.3	19.4	17.7	17.8	21.0
73	19.0	17.2	18.3	18.8	.....	20.8	15.8	18.4	19.5	18.2	18.4	19.3
74	16.7	16.1	17.0	16.9	15.5	18.2	14.9	16.0	17.5	16.4	16.5	14.2
76	18.7	17.9	18.0	17.7	17.3	20.8	16.0	17.1	18.2	18.2	18.1	17.6
77	18.6	17.7	17.6	17.9	16.5	18.9	16.0	16.5	18.0	18.3	17.5	18.3
78	15.1	15.3	15.8	14.7	14.1	16.3	13.6	15.1	16.4	15.2	15.2	12.9
79	17.2	17.1	16.1	17.9	17.2	18.1	15.3	16.9	18.5	18.1	17.3	.....
80	16.0	15.5	15.2	14.9	15.4	18.1	14.3	14.7	16.7	15.4	15.6	16.4
Mean of crosses	16.9	16.3	16.7	16.2	15.9	18.0	14.4	15.9	17.2	16.4	[b]16.4	.....
Kernel rows of parent [a]	.....	.....	13.6	15.1	13.0	19.0	12.1	14.6	15.9	15.2	.....	.....

[a] The data on the parent lines are not comparable with those on the crosses.
[b] Mean number of kernel rows per ear for all crosses in this experiment.

DISCUSSION

The relations studied may be considered more conveniently in groups comprising (1) correlations among characters within a single generation, (2) those between characters in the inbred parent lines and the same characters in the crossbred progenies, and (3) correlations between the various characters in the inbred parents and the yield of the crossbred progenies. The interpretation of the individual coefficients of correlation was discussed as the data were presented. Emphasis here will be placed upon the more general relations.

The coefficients of correlation among characters within the same generation indicate the extent to which the different characters were associated under the conditions of the experiment and the relative ease of obtaining various combinations of characters. Of the correlations within inbred lines and within F_1 crosses, always within the same generation, those of yield with the other characters are of most interest. The different characters (indicated by their symbols) which were correlated significantly with yield are listed in Table 27.

TABLE 27.—*Different characters (indicated by their symbols) which were correlated significantly with yield*

Inbreds, crosses, and individual parents compared	Characters correlated significantly with yield	
	Positively	Negatively
Within the inbred lines	ENOPS	BCDQ.
Within the F_1 crosses	ABEFGNOPS	IKQ.
Individual crosses and parents (1926 comparison of crosses)	ABEFGNOPX	Q.
Individual parents and mean yields of crossbred progenies (1926 and 1927 comparisons of crosses).	EFGX	Q.

In general, characters indicating vigor and size were correlated positively with yield in the inbred lines and in the crosses. The apparent exception, the reversal of relation for date of silking (B) in the two groups, probably is due to the fact that late silking among inbred lines frequently reflects a lack of inherent vigor. In the crosses, on the other hand, date of silking is more largely a measure of relative earliness. The negative relation of yield and shrinkage of the harvested ears (C) in the inbred lines is another expression of this condition. The negative relation between yield and ear-shape index (Q) shows clearly that in these experiments the larger yields were composed of relatively long, slender ears.

The coefficients of correlation between characters in the inbred parent lines and the same characters in the crosses show the extent to which these parental characters were expressed in the crosses. They are of importance, therefore, in determining those characters for which selection in the inbred lines was more and less effective as a means of obtaining them in the crosses. These correlations fail to bring out differences in the prepotency of the different parent lines. Such differences can be observed only from detailed comparisons of the crosses of the individual parent lines.

All of the correlations between the same characters in the parent and in the progeny were positive. Those between characters of the inbred parents and the means for the same characters in the crossbred

progenies (Table 13) were very high, and indicate that, on an average, the characters of the parent were very definitely expressed in the crossbred progeny. Some parent lines impressed upon their crossbred progeny certain characters not expressed in the parents. In general, however, it appears that those inbred lines should be selected as parents whose characters conform most closely to those desired in the cross.

The coefficients of correlation between various characters in the inbred parent lines and the yield of the crossbred progenies indicate the degree to which these characters in the inbred parent influence the yield of the crossbred progeny. The different parental characters (indicated by their symbols) which were correlated significantly with yield of the crossbred progeny are listed in Table 27.

The positive correlations between yield in the crosses and so many of the characters in the inbred line which are indicative of plant vigor are encouraging. Most lines that have been inbred for a number of generations are lacking in vigor and productiveness to a degree which would make the commercial production of F_1 seed expensive. These correlations indicate that the most productive crosses may be expected from the most productive inbred parents. Large yields from the inbred parents will, of course, make for the most economical production of crossed seed.

There may be two more or less distinct objects in comparing inbred lines in different crossbred combinations: (1) To locate high-yielding individual F_1 crosses and (2) to locate inbred lines which give relatively high yields in all combinations. The immediate use intended for the inbred lines will determine the object of any particular comparison. If two inbred lines are wanted for use in an F_1 cross for commercial corn production, then the highest yielding combination may be desired. If the inbred lines are to be used in double crosses, multiple crosses, or in synthetic varieties, however, those lines which produce relatively high yields in practically all crossbred combinations would be the more promising.

Neither of two inbred parent lines which happen to "nick" well need carry many dominant favorable factors. It is only necessary that the few such factors they do carry supplement each other. It would not be expected, however, that such a condition would result in these lines producing high-yielding crosses in many different combinations. Inbred lines which produce high yields in most of the crosses in which they are used either must carry a few uncommon but important dominant favorable factors which supplement those brought in by the general run of inbred lines in the experiment, or they must carry many of the common dominant favorable factors. In either event, the highest yields would be expected to be found among the crosses between lines both of which produced high-yielding crosses in many combinations.

From the data presented on yield (Tables 15 to 19), it is evident that inbred lines differ greatly in their ability to produce high-yielding crosses. Some inbred lines (14, 25, 66, 112, and 135) produced high-yielding crosses in practically all combinations. Other lines (10, 31, 68, 102, and 141) produced some high-yielding crosses and some low-yielding crosses. Still other lines (3, 21, 67, 104, and 159) produced crosses practically all of which were low-yielding. Those lines whose crosses had low mean yields produced few high-yielding individual

combinations. In discarding these lines on the basis of the means of their crossbred progenies, therefore, there would be small chance of eliminating superior germ plasm. What has been said of yield is true also of the other characters studied.

The uniformly high yields of the crosses of some of the inbred lines are very encouraging as an indication of what may be expected from the corn-breeding program under way. The prepotency shown by the different lines in their F_1 crosses suggests that even after only three or four generations of selfing the lines must be homozygous for many of the factors that make for yield and other desirable characters. The higher yielding crosses do not appear to have been random combinations but occurred very definitely among the crosses by certain outstanding parent lines. On the basis of these yield comparisons, it seems possible to predict with reasonable assurance that future crosses by some of the lines tested will outyield comparable crosses by many of the other lines, so that the latter may be discarded without danger of serious loss. Furthermore, the crosses among the better lines retained should be more productive, on an average, than those so far compared, and new combinations among the better parent lines from the different groups may be superior to any so far obtained.

SUMMARY

Coefficients of correlation are reported (1) among characters within the same generation in inbred lines of corn and in F_1 crosses between inbred lines, (2) between characters of the inbred parent lines and the same characters in the crossbred progeny, and (3) between characters of the inbred parent lines and the yield of the crossbred progeny.

Within the inbred lines yield was correlated significantly and positively with plant height, number of ears per plant, ear length, ear diameter, and shelling percentage, and it was correlated significantly and negatively with date of silking, shrinkage of the harvested ears, chlorophyll grade, and ear-shape index.

Within the F_1 crosses yield was correlated significantly and positively with date of tasseling, date of silking, plant height, number of nodes per plant, number of nodes below ear, number of ears per plant, ear length, ear diameter, and shelling percentage, and it was correlated significantly and negatively with percentage of plants smutted, percentage of ears moldy, and ear-shape index.

Positive correlations between characters in the inbred parents and the same characters in the crossbred progeny were obtained for all of the 19 different characters studied. The correlations between characters of the inbred parent and the mean values of the same characters in the crossbred progeny were sufficiently high in many cases to be of value for predictive purposes.

Yield of the F_1 cross was correlated significantly and positively with the following characters in the parents: Date of tasseling, date of silking, plant height, number of nodes per plant, number of nodes below ear, number of ears per plant, ear length, ear diameter, and yield. It was correlated significantly and negatively with ear-shape index in the parents.

The mean yield of the crossbred progeny was correlated significantly and positively with plant height, number of nodes per plant, number of nodes below ear, and yield of the inbred parent line.

Different inbred lines showed marked differences in prepotency for practically all of the characters studied.

The high-yielding crosses do not appear to have been chance combinations but occurred very definitely among the crosses by certain outstanding parent lines.

The extreme productivity of the crosses of some of the inbred lines included in these experiments is promising and indicates what may be expected from this program of corn breeding.

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